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TURNAROUND OPERATIONS ANALYSIS FOR OTV

FINAL REPORT
VOLUME IV
WBS, DICTIONARY, AND COST METHODOLOGY

February 1988

GENERAL DYNAMICS
Space Systems Division

GDSS-SP-87-018

Turnaround Operations Analysis for OTV

Final Report

Vol. IV WBS and Dictionary and Cost Methodology

February 1988

The cost estimates contained herein represent technical and programmatic definition developed to date and may change as further technical information becomes available. These estimates are for planning purposes only and do not constitute a commitment on the part of General Dynamics.

Prepared for

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FORWORD

This study report was prepared by General Dynamics Space Systems (GDSS) Division for the National Aeronautics and Space Administration/Marshall Space Flight Center (NASA/MSFC) in accordance with Contract NAS8-36924, Data Requirement Number DR-4. The results were developed from August 1986 to January 1988.

This volume documents the Work Breakdown Structure (WBS) and WBS Dictionary and a discussion of the cost methodology and ground rules employed for the cost analysis conducted during this study.

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SUMMARY

The Turnaround Operations Analysis for Orbital Transfer Vehicles (OTV) Study was conducted by General Dynamics Space Systems Division (GDSS), Contract No. NASA8-36924, under the direction of the National Aeronautics and Space Administration (NASA)/Marshall Space Flight Center (MSFC).

The basic study was for 12 months with an add-on which brought the total time to 18 months. The results of the total study are presented in this final report.

The objectives and accomplishments during this study were to adapt and apply the newly created database of Shuttle/Centaur ground operations. Previously defined turnaround operations analyses were to be updated for ground-based OTVs (GBOTVs) and space-based OTVs (SBOTVs), design requirements identified for both OTV and Space Station accommodations hardware, turnaround operations costs estimated, and a technology development plan generated to develop the required capabilities.

The study provided technical and programmatic data for NASA pertinent to OTV ground and space operations requirements, turnaround operations, task descriptions, timelines and manpower requirements, OTV modular design and booster and Space Station interface requirements, OTV & Space Station accommodations design and operations requirements, SBOTV accommodations development schedule, cost and turnaround operations requirements, and a technology development plan for ground and space operations and space-based accommodations facilities and support equipment. Significant conclusions of the effort were:

a. Shuttle/Centaur Lessons Learned

   1. Semi-automated cryo stage can be extended to full automation
   2. Identified manual operations: candidates for automation
   3. Airborne support equipment (ASE) for ground-based cargo bay OTV will be complex (dump and dual fault tolerant)
   4. Dedicated facility recommended
   5. Facility should provide capability to simulate launch vehicle interfaces and Space Station interfaces
   6. Reduce number of moves

b. Ground Processing Operations for GBOTVs

   1. Ground processing of ground-based cargo bay OTVs nearly identical to Shuttle/Centaur

   2. Ground processing of ground-based unmanned cargo vehicle (UCV) OTVs similar to Atlas/Centaur and Shuttle/Centaur

   3. Ground processing of space-based OTV relatively simple
      (a) Simple ASE
      (b) No orbiter cryo integration
      (c) No payload integration

4. Recommend integrated processing facility for GBOTVs: Two shift operations

5. Automated ground processing operations where possible

6. GBOTV initial launch 6 weeks (9200 manhours)

7. Nominal turnaround GBOTV 5 weeks + mission (7800 manhours)

8. UCV OTV initial launch 5 weeks (6500 manhours)

9. UCV OTV nominal turnaround 5 weeks + mission (6200 manhours)

10. Recommend shared ground processing facility for SBOTV

c. Ground Processing Operations SBOTV

1. Ground processing of space-based OTV relatively simple
   (a) Simple ASE
   (b) No orbiter cryo integration
   (c) No payload integration

2. Recommend shared ground processing facility for SBOTV

3. SBOTV single shift operations - Initial Launch 11 weeks (10,332 manhours)

d. Space Processing Operations SBOTV

1. SBOTV can be based at Space Station and turned around in safe and cost-effective manner

2. Use teleoperations for SBOTV turnaround tasks except for aerobrake thermal protection system: extravehicular activity (EVA)

3. Nominal turnaround for SBOTV:
   (a) 63 manhours in space
   (b) 763 manhours on ground
   (c) 7 days + mission

4. SBOTV turnaround propellant resupply, support equipment maintenance, and long-term cryogenic facility maintenance = 1273 manhours per year average at the Space Station (3 men maximum per task)

e. OTV Design and Interfaces

1. Need proposed modular design of SBOTV to meet projected turnaround times

2. Interfaces between OTV launch vehicle and accommodations have been identified

f. Space Station Design, Support, and Interface Requirements

1. SBOTV accommodations/support equipment and interfaces with the Space Station have been identified

2. Minimum scars required on initial Space Station for SBOTV accommodations

g. Support Equipment Development Cost and Schedule

1. Development of OTV accommodations technology requires
   (a) Analyses, tests, and simulations on the ground
   (b) A cryogenic experiment on an expendable launch vehicle (ELV) in space, and Shuttle sortie missions for maintenance/servicing experiment
   (c) A maintenance/servicing Technology Development Mission (TDM) and possibly a cryogenic TDM at the Space Station

2. $1.4 billion development cost for OTV accommodations/support equipment for SBOTV initial operating capability (IOC) in 2001

h. Turnaround Operations Costs. Average $34M per year for on-orbit tasks to turnaround a SBOTV

i. Technology Development Plan. The following is the priority listing of the technologies needed to be developed for a SBOTV:

1. Propellant transfer, long-term storage, and reliquefaction
2. Automated fault detection/isolation and checkout system
3. Docking and berthing
4. Maintenance/servicing operations and facilities/support equipment
5. Payload mating/interface

j. Propellant Transfer, Long-Term Storage, and Reliquefaction Technology Development Requirements

1. Analyses, simulation and ground testing

2. An orbital experiment launched on an ELV with a H_2 tank scale factor between 0.1 and 0.4

3. Depending on the scale factor on the ELV experiment which produces different confidence levels of extrapolation to full scale, these options are seen to be able to reach operational capability
   (a) 0.4-scale ELV (Titan IV) can lead to direct development of operational system
   (b) 0.1-scale ELV (Atlas/Centaur) would require additional full-scale ground testing, or
   (c) Full scale H_2 tank testing at the Space Station

A. Too early to recommend which approach should be pursued

k. Automated Facility Detection/Isolation and Checkout System. Development of GBOTV and SBOTV operation technology requires analyses, simulation, and ground testing of automated fault detection/isolation and checkout system.

l. Maintenance/Servicing Operations and Facilities/Support Equipment. Development of SBOTV accommodations technology requires analyses, simulation, ground testing, and Shuttle sortie missions, and a Space Station TDM for docking and berthing, maintenance/servicing, operations/support equipment, and payload mating/interface.

SECTION 1

INTRODUCTION

The Orbital Transfer Vehicle (OTV) Concept Definition and System Analysis Studies, and earlier Space Station Architecture Studies, have shown that space-based OTVs (SBOTVs) offer potential economic benefits over ground-based OTVs (GBOTVs). In addition, the Definition of Technology Development Missions for Early Space Station -- OTV Servicing Study, completed in 1984 and the present OTV Concept Definition Studies have generated preliminary operational scenarios and requirements for SBOTVs.

The General Dynamics Space Systems Division (GDSS) OTV Servicing Study used our Eastern Test Range (ETR) Atlas/Centaur processing as a data base. This has provided a sound background for a preliminary projection of activities to maintain and service an upper stage in space. Recently, the design, launch processing, and manufacture of the Shuttle/Centaur was essentially completed. The launch processing was performed up to taking the stage out to the launch pad before the program was cancelled. The Centaur, redesigned for increased performance and Shuttle integration requirements, is closer to an OTV than the vehicle used on Atlas.

Now that the Shuttle/Centaur integrated test planning data and launch processing has been completed, GDSS has used this information as the data base for the conduct of this follow-on study. Processing information has been updated with this new data. In addition, with this new data, it was possible to provide more detailed information on the most desirable methods for turning around an SBOTV at the Space Station, the support personnel and equipment needed, and the operations costs. The Shuttle/Centaur data base -- that of a cryogenic upper stage launched from the Shuttle -- has provided National Aeronautics and Space Administration (NASA) a comprehensive, substantiated turnaround approach for Space Station/OTV planning.

The Space Transportation Architecture Studies (STAS) currently being performed for NASA and Department of Defense (DoD) have placed strong emphasis on the reduction of operations costs through simplification, automation, etc. This turnaround operations analysis study provides additional information to support the pursuit of this cause in the upper-stage area.

1.1 OBJECTIVES

The basic objectives of this study are to adapt and apply the newly created data base of Shuttle/Centaur ground operations planning to update previously defined turnaround operations analyses for GBOTVs and SBOTVs, identify design requirements for both OTV and Space Station accommodations hardware, and estimate turnaround operations costs. Specific objectives which support these basic objectives are as follows:

a. Define OTV turnaround operations requirements, concepts, and scenarios.

b. Conduct operations functional and task analyses.

c. Assess the impact of OTV turnaround operations on ground facilities and Space Station design and support requirements.

d. Identify OTV design requirements of effective turnaround operations.

e. Analyze turnaround operations costs and identify operations costs drivers.

f. Generate Technology Development Plan.

1.2 GROUND RULES AND GUIDELINES

The following ground rules and guidelines were used in the performance of this study:

a. Make maximum use of prior and current projects.

b. Space Shuttle will be the Earth launch vehicle: $100M [Eastern Launch Site (ELS)].

c. Revision 8 nominal mission model.

d. Space Station Initial Operational Capability (IOC) 1994.

e. Orbital Maneuvarable Vehicle (OMV) will be available.

f. Orbiter Cargo Bay (OCB), Aft Cargo Carrier (ACC), and Unmanned Cargo Vehicle (UCV) Launched
GBOTVs

g Reference SBOTV configuration: Defined by Marshall Space Flight Center (MSFC) for Space Station Phase B.

h. SBOTV life is 40 missions.

i. Definition of a Task: Any activity or collection of activities serving a specified purpose relative to turnaround of the OTV.

j. Definition of a Resource: Any quantity required for the performance of a task: Each resource will be defined to appropriate depth for concept definition.

k. Functional tasks will be completely defined.

l. Tasks sequencing information will be provided.

m. Functional/task data base compatible with government computers.

1.3 OTV MISSIONS

The OTV will accomplish a wide range of missions, from Earth orbital to lunar and planetary, both unmanned and manned. (See Figure 1-1.) Routine transfer of civilian and military payloads between low Earth and geosynchronous orbit are planned, including delivery, retrieval, and in-place servicing. The operational scenario and mission profile of the OTV include: initial delivery of the OTV with subsequent delivery of payloads and propellants from the Earth to the OTV/servicing facility by either the Space Transportation System (STS) of unmanned launched vehicles; integration of payloads on the OTV and refueling of the OTV from propellant storage tanks on the servicing facility; departure of the OTV and payloads to high orbits, translunar, or interplanetary trajectories; then return of the OTV via aerobraking to the servicing facility.

Earth orbital

- Multiple GEO payload delivery
- Large GEO satellite delivery
- GEO satellite retrieval
- Experimental GEO platform
- GEO shack elements
- Manned GEO sortie
- GEO shack logistics
- DoD

Beyond earth

- Unmanned planetary
- Unmanned lunar orbit
- Unmanned lunar surface
- Lunar orbit station
- Manned lunar sorties/logistics

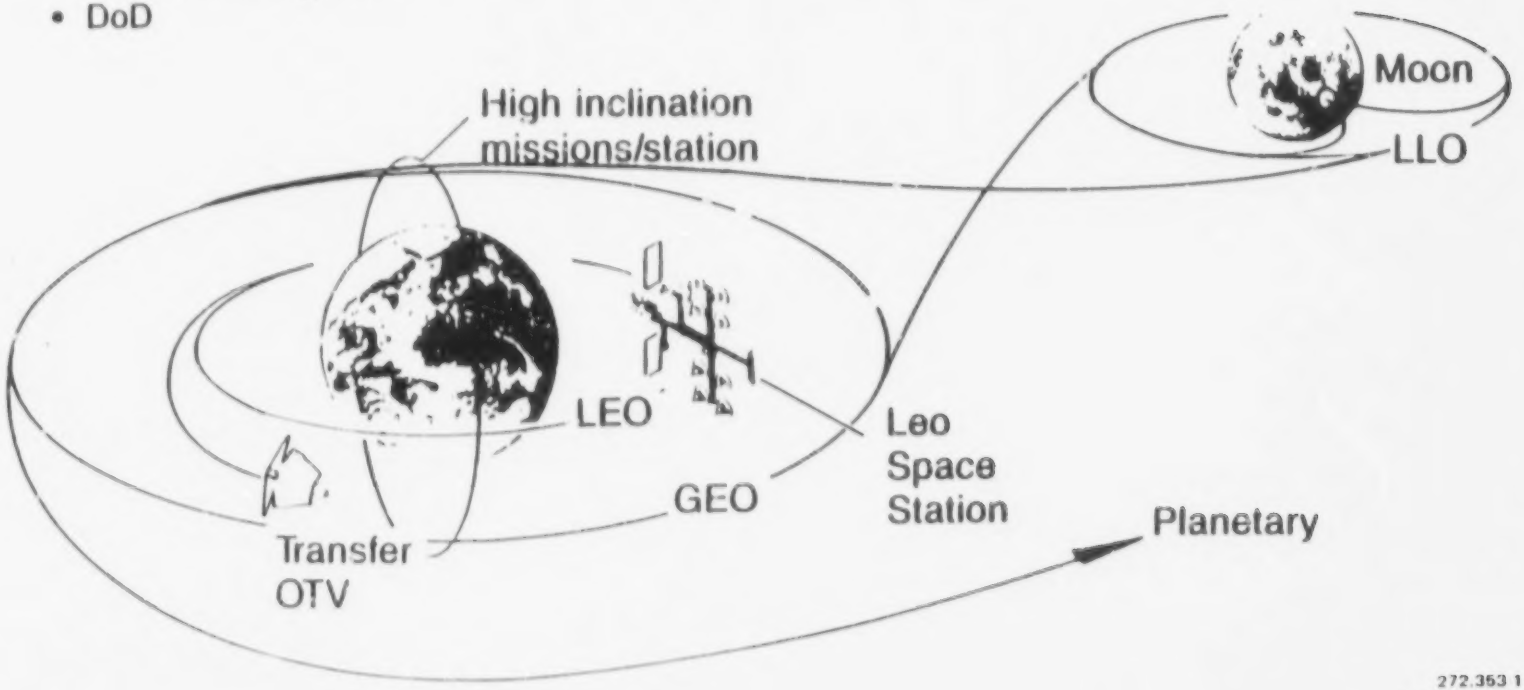

Figure 1-1. OTV Missions

For purposes of this study, NASA has specified that the NASA/MSFC Revision 8 nominal mission model be used. Figure 1-2 indicates the number of missions to be performed each year for Revision 8 and when the major mission drivers first occur.

1.4 STUDY APPROACH

The overall approach to this study will be a step-wise translation of Shuttle/Centaur launch processing experience to: 1) an expendable GBOTV, 2) a reusable GBOTV, and 3) a reusable SBOTV. (See Figure 1-3.) Each step will be separately defined to allow a clear delineation of the functions and requirements which are peculiar to each vehicle/basing mode. The major differences between each step are called out to the right of the blocks.

This approach provides more insight for extrapolation from Shuttle/Centaur launch processing to a reusable SBOTV.

Figure 1-4 presents the study schedule, delineating the tasks to be performed and the program reviews. The technical work was accomplished in 16 months with the reporting completed in 18 months.

To accomplish the study objectives, OTV turnaround operations requirements, concepts, and scenarios were defined; operations functional and task analyses were conducted; the impact of OTV turnaround operations on Space Station design and support requirements was assessed; OTV design requirements for effective turnaround operations were identified; turnaround operations costs were analyzed; and operations cost drivers were identified. In addition, a technology development plan was generated to develop the capability to process both GBOTVs and SBOTVs.

1.4.1 TASK 1 - GROUND AND SPACE OPERATIONS REQUIREMENTS. The Shuttle/Centaur ground processing data base was used to assess and identify requirements for OTV processing. As we evaluated the data base, we determined which operational functions were Centaur peculiar and which ones were required for OTV processing. The data consisted of operations plans which established the processing and critical paths for Shuttle/Centaur at the ELS. The plan had about 155 tasks defined and listed about 90 procedures to be accomplished during Centaur processing, before it was transported to the vertical processing facility. The operations plans for the vertical processing facility and Complex 39 were also assessed. This was the type of data that we used to determine if all processes had been identified in the current OTV space-based operations. We then updated the OTV data previously defined to include the requirements identified here.

The Shuttle/Centaur data base also included manpower loading for each task and equipment requirements.

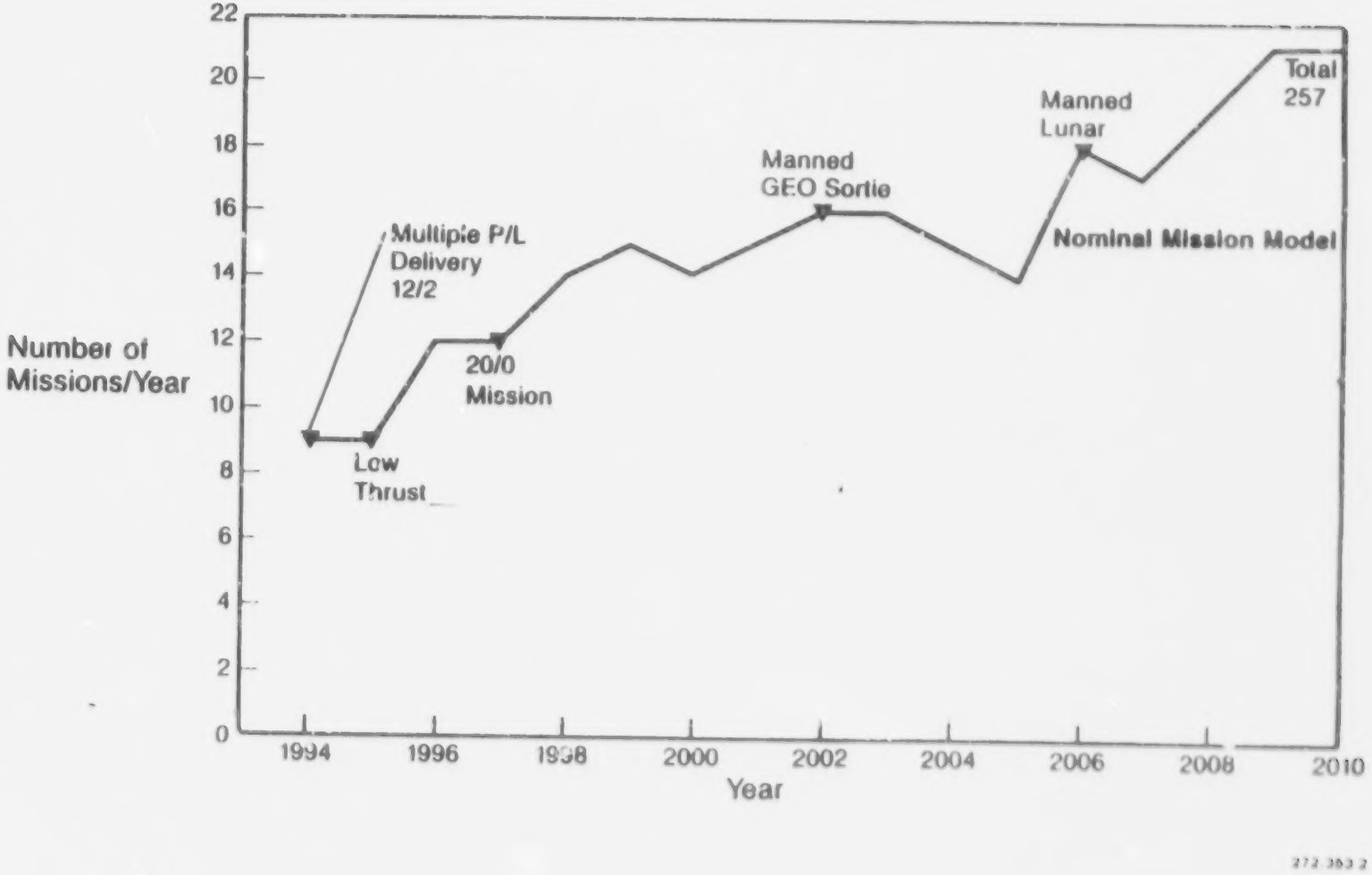

Figure 1-2. Revision 8 Mission Model

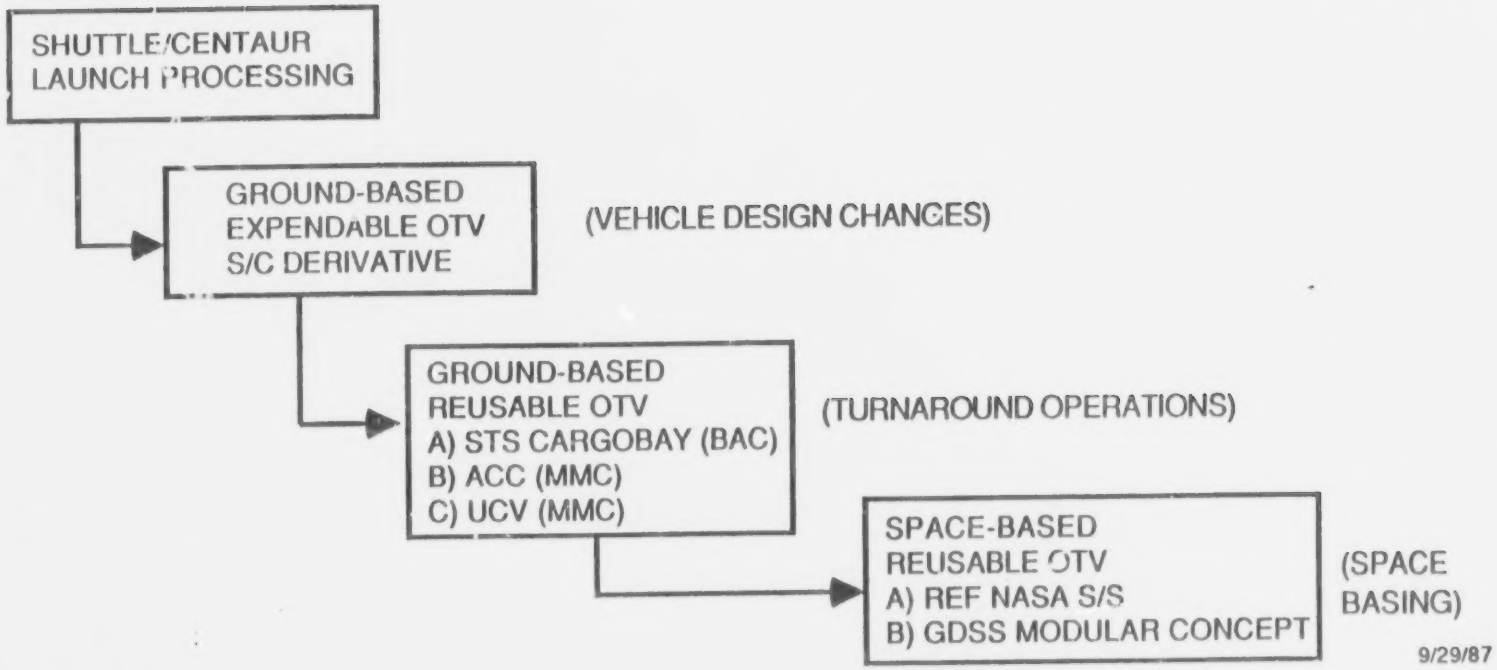

Figure 1-3. Approach

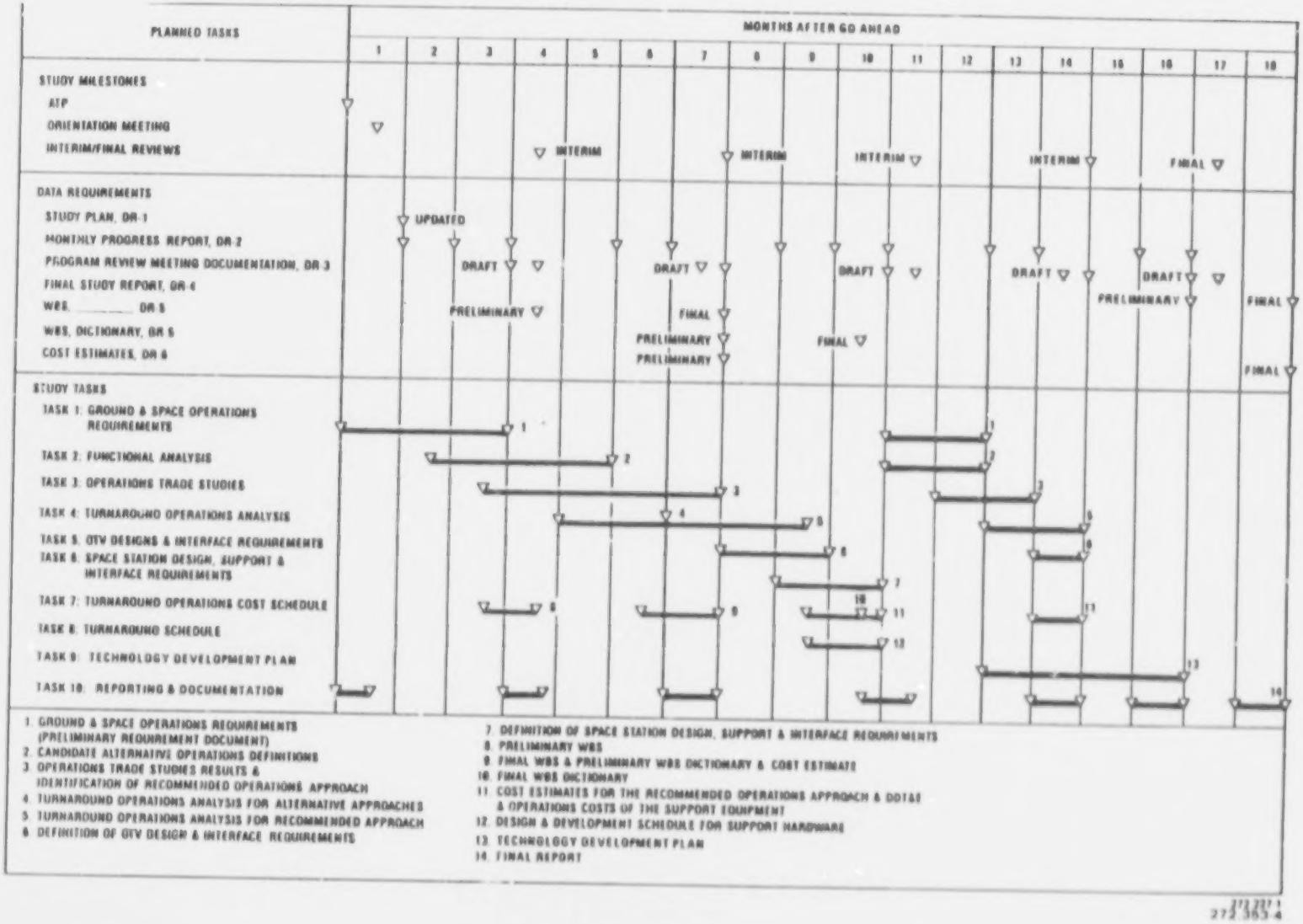
PLANNED TASKS
MONTHS AFTER GO AHEAD
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
STUDY MILESTONES
ATP
ORIENTATION MEETING
INTERIM/FINAL REVIEWS
INTERIM
INTERIM
INTERIM
INTERIM
FINAL
DATA REQUIREMENTS
STUDY PLAN, DR 1
MONTHLY PROGRESS REPORT, DR 2
PROGRAM REVIEW MEETING DOCUMENTATION, DR 3
FINAL STUDY REPORT, DR 4
WBS, _____ DR 5
WBS, DICTIONARY, DR 5
COST ESTIMATES, DR 6
UPDATED
DRAFT
PRELIMINARY
DRAFT
FINAL
PRELIMINARY
PRELIMINARY
DRAFT
FINAL
DRAFT
DRAFT
PRELIMINARY
DRAFT
FINAL
FINAL
STUDY TASKS
TASK 1: GROUND & SPACE OPERATIONS REQUIREMENTS
TASK 2: FUNCTIONAL ANALYSIS
TASK 3: OPERATIONS TRADE STUDIES
TASK 4: TURNAROUND OPERATIONS ANALYSIS
TASK 5: OTV DESIGNS & INTERFACE REQUIREMENTS
TASK 6: SPACE STATION DESIGN, SUPPORT & INTERFACE REQUIREMENTS
TASK 7: TURNAROUND OPERATIONS COST SCHEDULE
TASK 8: TURNAROUND SCHEDULE
TASK 9: TECHNOLOGY DEVELOPMENT PLAN
TASK 10: REPORTING & DOCUMENTATION
1 GROUND & SPACE OPERATIONS REQUIREMENTS (PRELIMINARY REQUIREMENT DOCUMENT)
2 CANDIDATE ALTERNATIVE OPERATIONS DEFINITIONS
3 OPERATIONS TRADE STUDIES RESULTS & IDENTIFICATION OF RECOMMENDED OPERATIONS APPROACH
4 TURNAROUND OPERATIONS ANALYSIS FOR ALTERNATIVE APPROACHES
5 TURNAROUND OPERATIONS ANALYSIS FOR RECOMMENDED APPROACH
6 DEFINITION OF OTV DESIGN & INTERFACE REQUIREMENTS
7 DEFINITION OF SPACE STATION DESIGN, SUPPORT & INTERFACE REQUIREMENTS
8 PRELIMINARY WBS
9 FINAL WBS & PRELIMINARY WBS DICTIONARY & COST ESTIMATE
10 FINAL WBS DICTIONARY
11 COST ESTIMATES FOR THE RECOMMENDED OPERATIONS APPROACH & DDT&E & OPERATIONS COSTS OF THE SUPPORT EQUIPMENT
12 DESIGN & DEVELOPMENT SCHEDULE FOR SUPPORT HARDWARE
13 TECHNOLOGY DEVELOPMENT PLAN
14 FINAL REPORT

Figure 1-4. Study Schedule

1.4.2 TASK 2 - FUNCTIONAL ANALYSIS. The requirements identified in Task 1 were integrated with other requirements such as guidelines and ground rules, Space Station configuration baseline, the SBOTV concept defined by NASA/MSFC to arrive at probable scenarios for processing. We looked at these requirements and determined whether they were essential for maintaining and operating an OTV. Any potential tall poles were identified, and all functional requirements were documented. The functional analysis includes the operations necessary to assemble a SBOTV on-orbit, space-based turnaround operations, servicing/maintenance, payload integration, launch and retrieval operations. We assessed these functions and incorporated any new requirements that were essential and appropriate and deleted or modified those that were not appropriate.

We formulated alternative scenarios from the functional requirements and defined operational methods for accomplishing each alternative scenario. These methods incorporated alternative means to accomplish each task, such as different types of facilities and automation for ground processing and different kinds of crew involvement, extravehicular activity (EVA) or intravehicular activity (IVA), and mechanized alternatives such as teleoperations, automatic disconnects on the vehicle, robotics, or a combination for SBOTV. These alternatives and the designated GBOTV concepts were compared in a trade study analysis to select a recommended approach in Task 3.

1.4.3 TASK 3 - OPERATIONS TRADE STUDIES. In this task we compared the attributes of each alternative operation identified in Task 2 to select a recommended approach. We defined the selection criteria used to evaluate the alternative operations. These criteria included design, operational, and cost factors that have an impact on the selection of a recommended approach. This task relied on inputs from Tasks 4 and 7 to provide adequate supporting data for evaluation of the approaches. The alternatives and selection criteria were then presented in a trade comparison matrix. The recommended operations approach was selected using the data from this matrix.

1.4.4 TASK 4 - TURNAROUND OPERATIONS ANALYSIS. This task generated the timeline analyses for both ground and space processing based on the requirements and alternative operational definitions derived in Tasks 1 and 2. These analyses provided the OTV turnaround operations data necessary to support the trade studies and to develop to more detail the trade study recommended operations by defining the ground-based and space-based resources.

We updated the existing OTV timelines to meet new requirements and created new timelines for new alternative functions. The timelines include OTV turnaround operations on the ground and in space and the maintenance of any identified Space Station OTV accommodations, such as orbital support equipment. Our timelines were created from data that was developed on task analysis worksheets. The task analysis worksheets are on computer disc and are used to document the pertinent detailed tasks, task durations, and resulting manhours. We also provided data to an appropriate level on task description sheets. The task description sheet has the task identification code, task descriptor, purpose, task description, task duration and frequency, and the resource requirements.

1.4.5 TASK 5 - OTV DESIGN AND INTERFACE REQUIREMENTS. Using the results and recommendations of the turnaround operations analysis and the definition of the baseline GBOTV and SBOTV, we identified and defined OTV design and interface requirements for basing on the ground and at the Space Station. These covered the areas of accessibility, modularity, size, and weight of Orbital Replacement Units (ORUs); ORU attachment and removal provisions; controlled storage; self-test to the ORU or subsystem level; handling and mating provisions; payload mating provisions; accommodations for mechanical, fluid, and electrical disconnects; zero-g propellant transfer; and management system, etc.

1.4.6 TASK 6 - SPACE STATION DESIGN, SUPPORT AND INTERFACE REQUIREMENTS. Using the definition of the space-based support equipment, the operational maintenance, checkout and launch requirements, the definition of an SBOTV to meet the operational and interface requirements, and the baseline Space Station functional and design concept, we performed a design requirements analysis to determine the accommodation needs from the Space Station to support the SBOTV. This entailed identifying the operational and physical Space Station support and interface requirements to accommodate the retrieval, maintenance, servicing, checkout, payload mating, and launching of the OTV. These included the mechanical, fluid and electrical interfaces; cg considerations; spares storage; pressurized volume; propellant transfer, and storage system; docking, berthing, and handling equipment; environmental protection; and crew support requirements.

1.4.7 TASK 7 - TURNAROUND OPERATIONS COST ESTIMATES. A WBS and WBS dictionary was developed which was used in the performance of the trade studies. The task's costs of the recommended operational approach considering the manpower resources required were estimated. The operational costs were divided into two categories: fixed and variable costs. Fixed costs are associated with a base cost not dependent on the number (within limits) of OTVs processed during a period of time (normally 1 year). Operation cost drivers were also identified. The design development test and evaluation (DDT&E) and operations costs of the support equipment for the recommended operational approach were also identified.

1.4.8 TASK 8 - TURNAROUND SCHEDULE. We developed a master program development schedule for the OTV and the evolution of the Space Station from IOC to the growth station which can support an SBOTV. From this, we generated a design and development schedule for the turnaround operations support hardware. The schedule included the technology development activities including analysis and ground testing, Shuttle sortie flights and Technology Development Missions (TDMs) required at the Space Station to develop the turnaround operations capability.

1.4.9 TASK 9 - TECHNOLOGY DEVELOPMENT PLAN. We generated an integrated technology development plan for the technologies required for ground and space processing OTVs. This was a single plan which defined the tests and experiments to be performed on the ground, on expendable flight experiments, on Space Shuttle sortie missions, and on the early Space Station. The ground processing technologies included: 1) fault detection/isolation and system checkout, 2) visual inspection, 3) leak check and detection, 4) documentation, and 5) facility checkout and operations provisions.

The space processing technologies included: 1) propellant transfer, storage, and reliquefaction, 2) OTV docking and berthing, 3) EVA operations, 4) OTV/payload mating, 5) maintenance facilities/support equipment, and 6) automated fault detection/isolation and system checkout. The plan included task objectives, requirements, mode of accomplishment, schedules, resources, operations, and expected products. The plan reflected and accommodated current and projected research and technology programs where appropriate.

1.5 OTV CONFIGURATION

Configurations evaluated for functional differences (See Figure 1-5) include Atlas/Centaur; Shuttle/Centaur, Shuttle/Centaur derivative expendable OTV; Boeing Ballute OCB launched reusable GBOTV: Martin ACC launched reusable GBOTV; and SBOTV (MSFC reference configuration). In addition the Martin UCV OTV (see Figure 1-6) was evaluated. The configurations will be shown in more detail in the following sections.

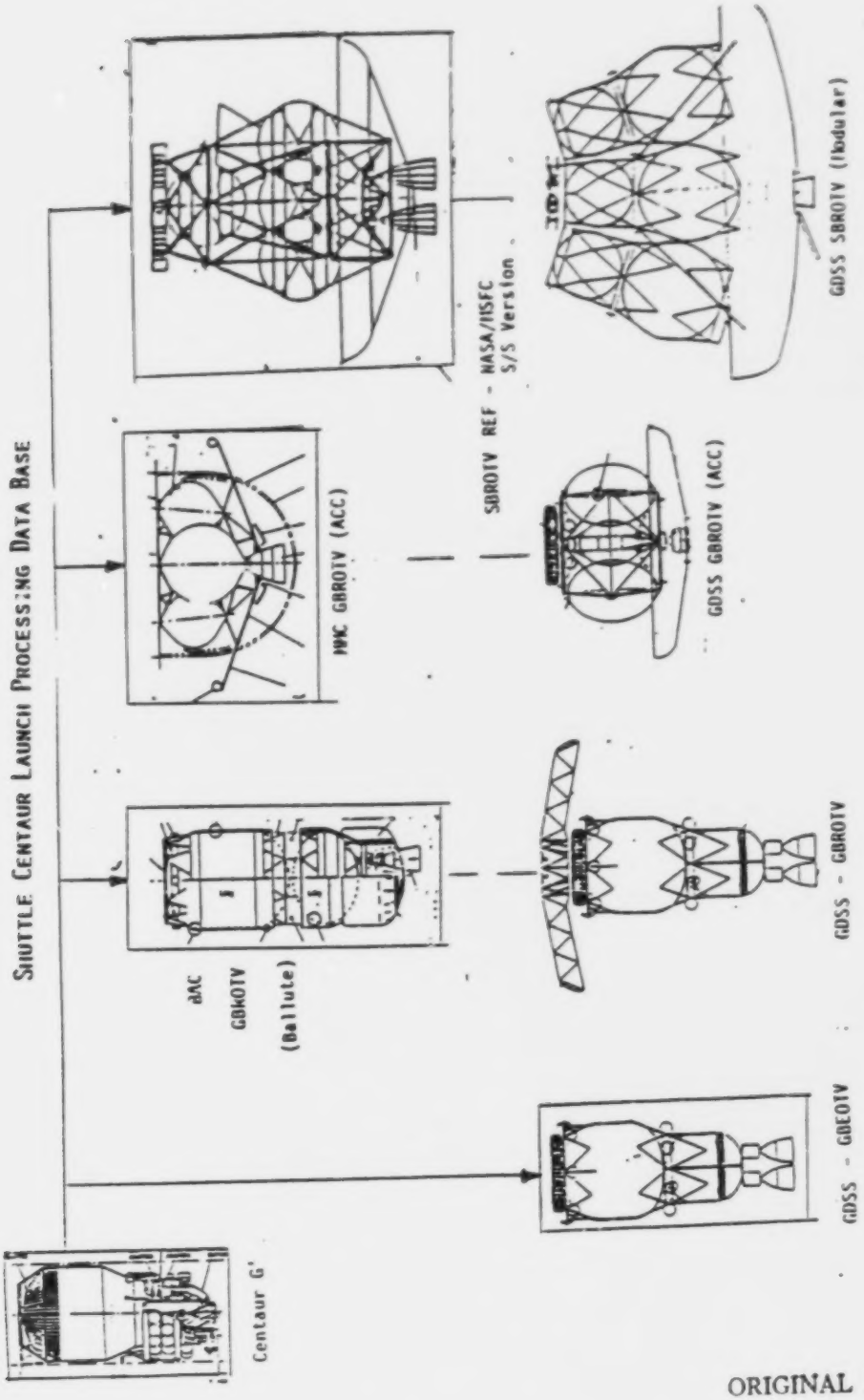

Figure 1-5. OTV Configurations

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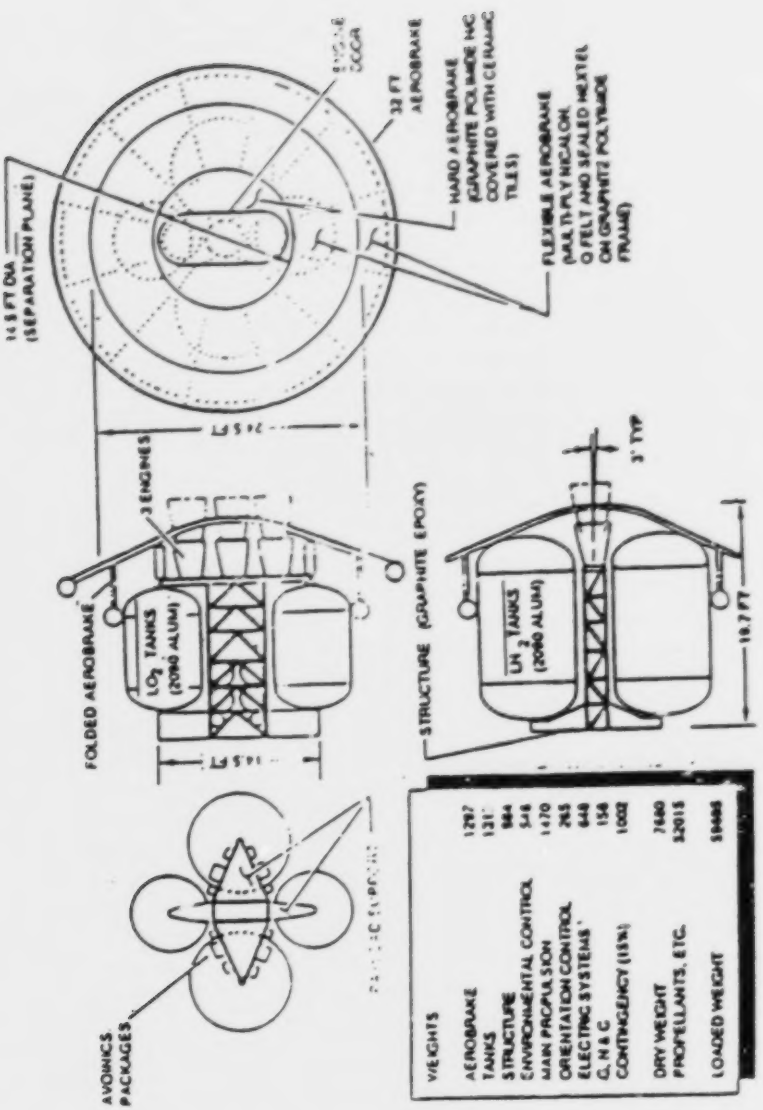

WEIGHTS	
AEROBRAKE	1797
TANKS	1211
STRUCTURE	984
ENVIRONMENTAL CONTROL	348
MAIN PROPULSION	1470
ORIENTATION CONTROL	265
ELECTRIC SYSTEMS	648
G, N & C	158
CONTINGENCY (15%)	1002
DRY WEIGHT	7480
PROPELLANTS, ETC.	32915
LOADED WEIGHT	40395

Figure 1-6. Unmanned Cargo Vehicle (UCV) OTV - Martin

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2.0 Work Breakdown Structure (WBS)

The WBS for the OTV Turnaround Operations are presented on the following pages. The WBS is a comprehensive breakdown of all elements of the program life cycle, categorized into several layers of hardware, software, facility and task-, function- or service-oriented end items which completely define the program. The WBS for the OTV Turnaround Operations is shown in Tables 1 and 2. The WBS is used to identify and establish each individual cost element for life-cycle cost modeling, and also forms a framework for program planning and scheduling. The WBS is structured to be applicable to each of the life-cycle time-phased activities, specifically concept exploration, demonstration/ validation, full-scale development, nonrecurring production, recurring production, and operations and support. A dictionary describing each WBS element is included following Table 2.

OTV TURNAROUND OPERATIONS WBS

GENERAL DYNAMICS
Space Systems Division

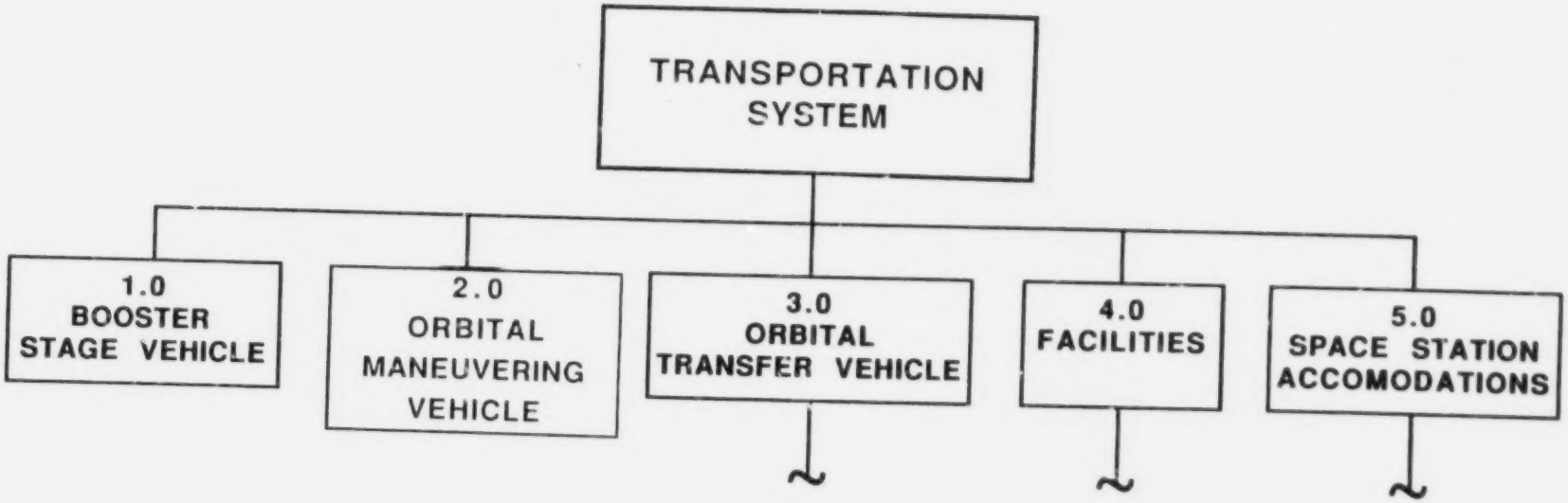


Table 1

OTV TURNAROUND OPERATIONS WBS

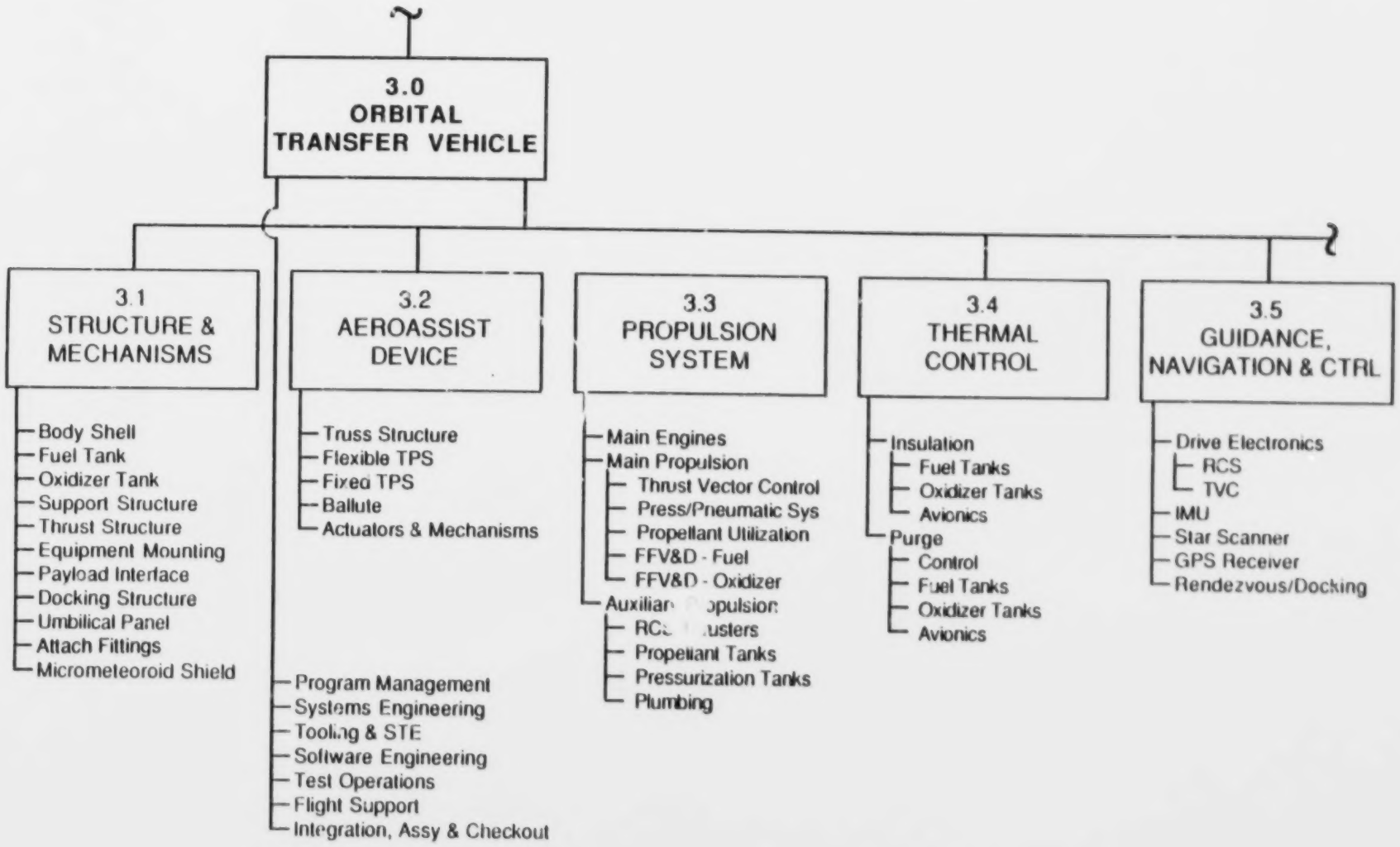
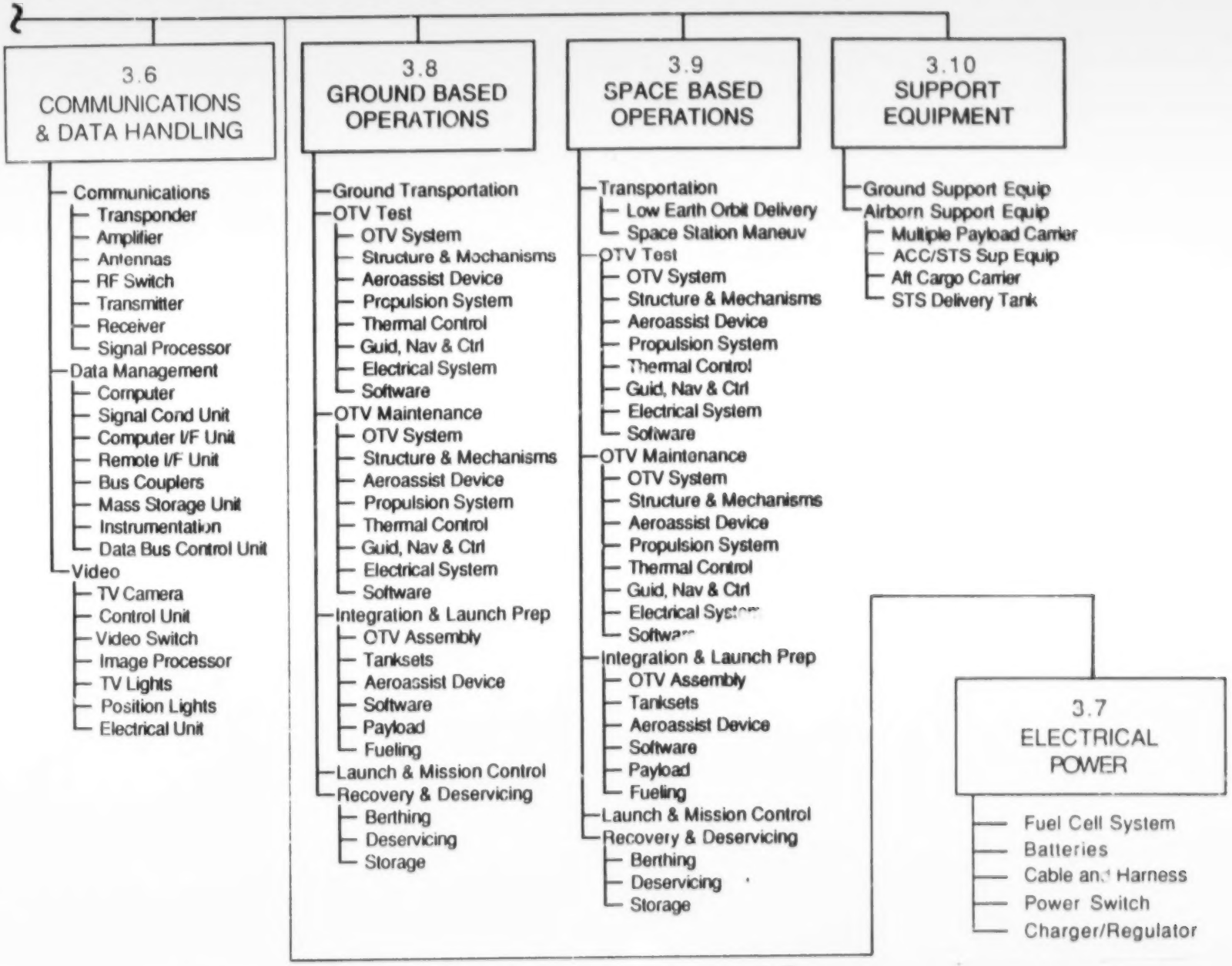


Table 1

OTV TURNAROUND OPERATIONS WBS

GENERAL DYNAMICS
Space Systems Division



OTV TURNAROUND OPERATIONS WBS

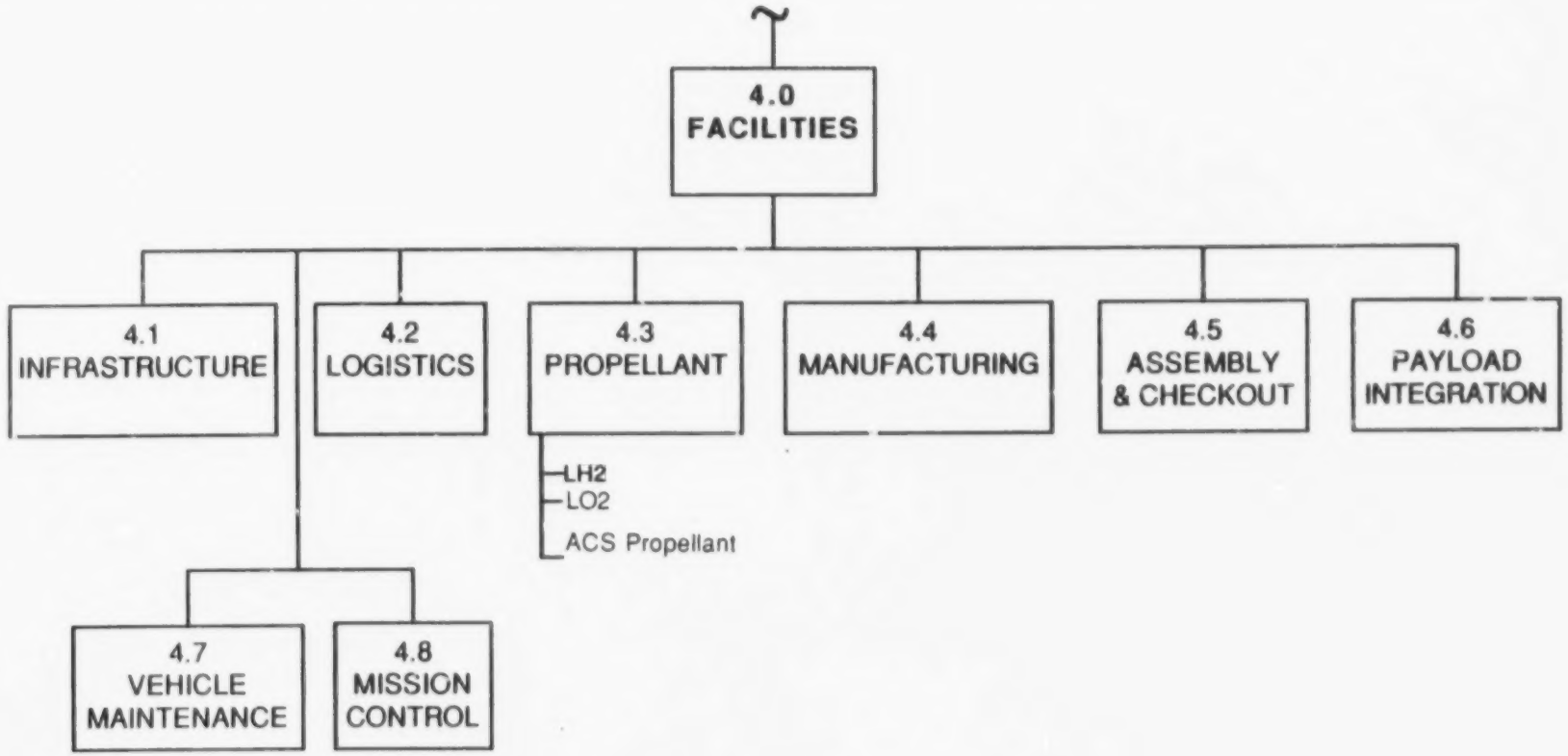


Table 1

OTV TURNAROUND OPERATIONS WBS

GENERAL DYNAMICS
Space Systems Division

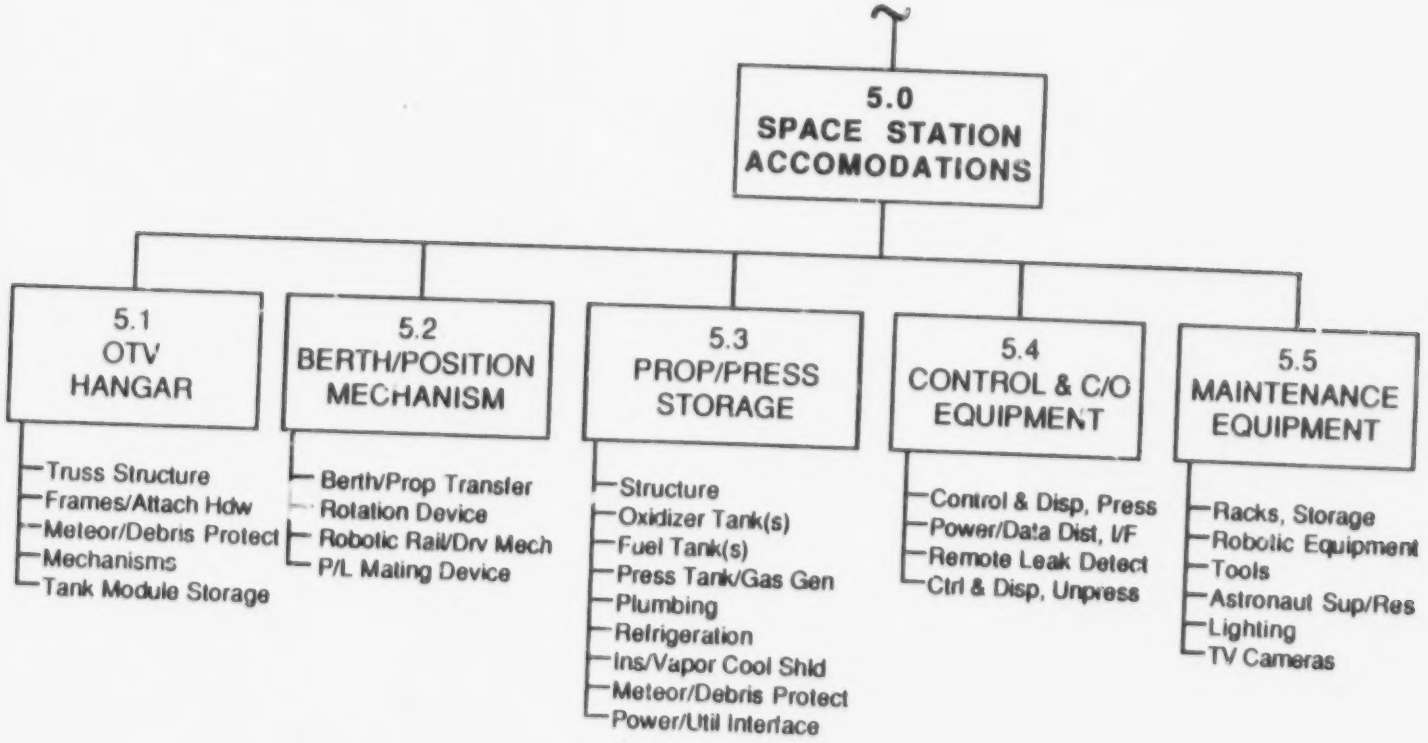


Table 1

WBS IDENTIFICATION	TECHNICAL & CONCEPT DEVELOPMENT	DDT & E					PRODUCTION	OPERATIONS		
		DESIGN & DEVELOPMENT	INITIAL SPARES	GROUND TEST H/W	FLIGHT TEST H/W	REFURB TO PROD UNIT	HARDWARE	SPARES	FLIGHT OPERATIONS	REFURB
3.0 ORBITAL TRANSFER VEHICLE										
3.0.1 Program Management										
3.0.2 Systems Engineering										
3.0.3 Tooling & STE										
3.0.4 Software Engineering										
3.0.5 Test Operations										
3.0.6 Flight Support										
3.0.7 Integration, Assy & C/O										
3.1 STRUCTURE & MECHANISMS										
3.1.1 Body Shell										
3.1.2 Fuel Tank										
3.1.3 Oxidizer Tank										
3.1.4 Support Structure										
3.1.5 Thrust Structure										
3.1.6 Equipment Mounting										
3.1.7 Payload Interface										
3.1.8 Docking Structure										
3.1.9 Umbilical Panel										
3.1.10 Orbiter Attach Fittings										
3.1.11 Micrometeroid Shield										
3.2 AEROASSIST DEVICE										
3.2.1 Truss Structure										
3.2.2 Flexible TPS										
3.2.3 Fixed TPS										
3.2.4 Ballute										
3.2.5 Actuators & Mechanisms										
3.3 PROPULSION SYSTEM										
3.3.1 Main Engines										
3.3.2 Main Propulsion										
3.3.2.1 Thrust Vector Control										
3.3.2.2 Press/Pneumatic System										
3.3.2.3 Propellant Utilization										
3.3.2.4 FFV&D - fuel										
3.3.2.5 FFV&D - oxidizer										
3.3.3 Auxiliary										
3.3.3.1 RCMs										
3.3.3.2 Propellant Tanks										
3.3.3.3 Pressurization Tanks										
3.3.3.4 Plumbing										
3.4 THERMAL CONTROL										
3.4.1 Insulation										
3.4.1.1 Fuel Tanks										
3.4.1.2 Oxidizer Tanks										
3.4.1.3 Avionics										

Table 2 - OTV Hardware Element and Cost Element Matrix

WBS IDENTIFICATION	TECHNICAL & CONCEPT DEVELOPMENT	DDT & E					PRODUCTION	OPERATIONS		
		DESIGN & DEVELOPMENT	INITIAL SPARES	GROUND TEST H/W	FLIGHT TEST H/W	REFURB TO PROD UNIT	HARDWARE	SPARES	FLIGHT OPERATIONS	REFURB
3.4.2 Purge										
3.4.2.1 Control										
3.4.2.2 Fuel Tanks										
3.4.2.3 Oxidizer Tanks										
3.4.2.4 Avionics										
3.5 GUIDANCE, NAVIGATION & CONTROL										
3.5.1 Drive Electronics										
3.5.1.1 RCS										
3.5.1.2 TVC										
3.5.2 IMU										
3.5.3 Star Scanner										
3.5.4 GPS Receiver										
3.5.5 Rendezvous/Docking										
3.6 COMMUNICATIONS & DATA HANDLING										
3.6.1 Communications										
3.6.1.1 Transponder										
3.6.1.2 Amplifier										
3.6.1.3 Antennas										
3.6.1.4 RF Switch										
3.6.1.5 Transmitter										
3.6.1.6 Receiver										
3.6.1.7 Signal Processor										
3.6.2 Data Management										
3.6.2.1 Computer										
3.6.2.2 Signal Conditioning Unit										
3.6.2.3 Computer I/F Unit										
3.6.2.4 Remote I/F Unit										
3.6.2.5 Bus Couplers										
3.6.2.6 Mass Storage Unit										
3.6.2.7 Instrumentation										
3.6.2.8 Data Bus Control Unit										
3.6.3 Video										
3.6.3.1 TV Camera										
3.6.3.2 Control Unit										
3.6.3.3 Video Switch										
3.6.3.4 Image Processor										
3.6.3.5 TV Lights										
3.6.3.6 Position Lights										
3.6.3.7 Electrical Unit										
3.7 ELECTRICAL POWER										
3.7.1 Primary Elecrical Power										
3.7.1.1 Fuel Cell System										
3.7.1.2 Batteries										
3.7.1.3 Cabling and Harness										
3.7.1.4 Distributor										
3.7.1.5 Power Switch										
3.7.1.6 Charger/Regulator										

Table 2 - OTV Hardware Element and Cost Element Matrix

WBS IDENTIFICATION	TECHNICAL & CONCEPT DEVELOPMENT	DDT & E					PRODUCTION	OPERATIONS		
		DESIGN & DEVELOPMENT	INITIAL SPARES	GROUND TEST HW	FLIGHT TEST HW	REFURB TO PRCD UNIT	HARDWARE	SPARES	FLIGHT OPERATIONS	REFURB
3.8 GROUND BASED OPERATIONS										
3.8.1 Ground Transportation										
3.8.2 OTV Test										
3.8.2.1 OTV System										
3.8.2.2 Structure & Mechanisms										
3.8.2.3 Aeroassist Device										
3.8.2.4 Propulsion System										
3.8.2.5 Thermal Control										
3.8.2.6 Guidance, Navigation & Ctrl										
3.8.2.7 Electrical System										
3.8.2.8 Software										
3.8.3 OTV Maintenance										
3.8.3.1 OTV System										
3.8.3.2 Structure & Mechanisms										
3.8.3.3 Aeroassist Device										
3.8.3.4 Propulsion System										
3.8.3.5 Thermal Control										
3.8.3.6 Guidance, Navigation & Ctrl										
3.8.3.7 Electrical System										
3.8.3.8 Software										
3.8.4 Integration & Launch Preparation										
3.8.4.1 OTV Assembly										
3.8.4.2 Tankers										
3.8.4.3 Aeroassist Device										
3.8.4.4 Software										
3.8.4.5 Payload										
3.8.4.6 Fueling										
3.8.5 Launch & Mission Control										
3.8.6 Recovery & Deservicing										
3.8.6.1 Berthing										
3.8.6.2 Deservicing										
3.8.6.3 Storage										
3.9 SPACE BASED OPERATIONS										
3.9.1 Transportation										
3.9.1.1 Low Earth Orbit Delivery										
3.9.1.2 Space Station Maneuvering										
3.9.2 OTV Test										
3.9.2.1 OTV System										
3.9.2.2 Structure & Mechanisms										
3.9.2.3 Aeroassist Device										
3.9.2.4 Propulsion System										
3.9.2.5 Thermal Control										
3.9.2.6 Guidance, Navigation & Ctrl										
3.9.2.7 Electrical System										
3.9.2.8 Software										

Table 2 - OTV Hardware Element and Cost Element Matrix

WBS IDENTIFICATION	TECHNICAL & CONCEPT DEVELOPMENT	DDT & E					PRODUCTION	OPERATIONS		
		DESIGN & DEVELOPMENT	INITIAL SPARES	GROUND TEST HW	FLIGHT TEST HW	REFURB TO PROD UNIT	HARDWARE	SPARES	FLIGHT OPERATIONS	REFURB
3.9.3 OTV Maintenance										
3.9.3.1 OTV System										
3.9.3.2 Structure & Mechanisms										
3.9.3.3 Aeroassist Device										
3.9.3.4 Propulsion System										
3.9.3.5 Thermal Control										
3.9.3.6 Guidance, Navigation & Ctrl										
3.9.3.7 Electrical System										
3.9.3.8 Software										
3.9.4 Integration & Launch Preparation										
3.9.4.1 OTV Assembly										
3.9.4.2 Tunksets										
3.9.4.3 Aeroassist Device										
3.9.4.4 Software										
3.9.4.5 Payload										
3.9.4.6 Fueling										
3.9.5 Launch & Mission Control										
3.9.6 Recovery & Deservicing										
3.9.6.1 Berthing										
3.9.6.2 Deservicing										
3.9.6.3 Storage										
3.9 SUPPORT EQUIPMENT										
3.10.1 Ground Support Equipment										
3.10.2 Airborn Support Equipment										
3.10.2.1 Multiple Payload Carrier										
3.10.2.2 ACC/STS Support Equipment										
3.10.2.3 Aft Cargo Carrier										
3.10.2.4 STS Delivery Tank										
4.0 FACILITIES										
4.1 INFRASTRUCTURE										
4.2 LOGISTICS										
4.3 PROPELLANT										
4.3.1 LH2										
4.3.2 LCH4										
4.3.3 LOx										
4.3.4 Attitude Control System										
4.4 MANUFACTURING										
4.5 ASSEMBLY & CHECKOUT										
4.6 PAYLOAD INTEGRATION										
4.7 VEHICLE MAINTENANCE										
4.9 MISSION CONTROL										
5.0 SPACE STATION ACCOMODATIONS										
5.1 OTV HANGAR										
5.1.1 Truss Structure										
5.1.2 Frames/Attach Hardware										
5.1.3 Meteor/Debris Protection										
5.1.4 Mechanisms										
5.1.5 Tank Module Storage										

Table 2 - OTV Hardware Element and Cost Element Matrix

WBS IDENTIFICATION	TECHNICAL & CONCEPT DEVELOPMENT	DOT & E					PRODUCTION	OPERATIONS		
		DESIGN & DEVELOPMENT	INITIAL SPARES	GROUND TEST H/W	FLIGHT TEST H/W	REFURB TO PROD UNIT	HARDWARE	SPARES	FLIGHT OPERATIONS	REFURB
5.2 BERTH/POSITION MECHANISM										
5.2.1 Berth/Propellant Transfer										
5.2.2 Rotation Device										
5.2.3 Robotic Rail/Drive Mechanism										
5.2.4 Payload Mating Fixture										
5.3 PROPELLANT/PRESSURE STORAGE										
5.3.1 Structure										
5.3.2 Oxidizer Tank(s)										
5.3.3 Feul Tank(s)										
5.3.4 Pressurization Tank/Gas Generator										
5.3.5 Plumbing										
5.3.6 Refrigeration										
5.3.7 Insulation/Vapor Cooled Shield										
5.3.8 Meteor/Debris Protection										
5.3.9 Power/Utilities Interface										
5.4 CONTROL CHECKOUT EQUIPMENT										
5.4.1 Control & Disp, Press										
5.4.2 Power/Data Distribution, I/F										
5.4.3 Remote Leak Detection										
5.4.4 Control & Disp, Unpress										
5.5 MAINTENANCE EQUIPMENT										
5.5.1 Racks, Storage										
5.5.2 Robotic Equipment										
5.5.3 Tools										
5.5.4 Astronaut Support/Restraint										
5.5.5 Lighting										
5.5.6 TV Cameras										

Table 2 - OTV Hardware Element and Cost Element Matrix

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
C	-100	TECHNOLOGY DEVELOPMENT	Refers to the cost of achieving technology readiness and demonstration. Contractor fee is excluded.
C	-200	DESIGN, DEVELOPMENT, TEST AND EVALUATION	This cost element includes the cost to develop the orbital transfer vehicle beginning with the conceptual and definition activities and concluding when the vehicle elements are ready for operational use. Included is the design, development, test and protoflight refurbishment of the flight hardware elements and associated ground and airborne support. Tooling, personnel training, systems engineering, facilities, software and program management are also included. It involves the application of scientific and engineering effort to transform an operational need into an operational system possessing the desired performance parameters. An iterative process of definition, synthesis, analysis, design, test and evaluation is utilized. Included in the effort is the integration of related technical parameters to assure compatibility of all physical, functional and program interfaces and to optimize the total system definition and design; along with the integration of reliability, maintainability, safety, human and other such factors into the total engineering effort. In addition to design and development of the airborne vehicle elements, costs include the acquisition of all Space Station accommodations, ground equipment, and facilities necessary to support the vehicle development, and tooling necessary for production of test vehicles. Contractor fee is excluded.
C	-210	DESIGN AND DEVELOPMENT	Includes the cost of interpreting OTV requirements and translating these requirements into the generation of design drawings, models, and other written and constructed representations that serve as a guide for the manufacture and test of OTV hardware. Involves the successive iteration of designs and models throughout the DDT&E phase, from conceptual design through full-scale development.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
C	-220	INITIAL SPARES	Includes the cost of manufacturing and assembling the vehicle hardware required for initial spares store.
C	-230	GROUND TEST HARDWARE	Includes the cost of manufacturing major vehicle and accommodations subsystems and complete elements needed for structural/dynamic testing, avionics system tests, propulsion system integration testing and all systems testing, including one set of ASE. Mock-ups and hardware for subsystem test and qualification are excluded from this element but are included with their design and development costs, as are special purpose test rigs. Propellants and gases are to be included with Ground Test Operations and excluded here.
C	-240	FLIGHT TEST HARDWARE	Includes the manufacturing cost of all test articles required for the flight test program such as the launch vehicle fuel tanks and airborne support equipment.
C	-250	PROTOFLIGHT REFURBISHMENT	Refers to the cost of refurbishing flight test hardware in a protoflight program for operational use after the test flight program.
C	-300	PRODUCTION	Includes the cost of manufacturing the orbital transfer vehicle units, produced after the initial protoflight unit. It includes the cost of hardware manufacturing, integration, assembly and checkout for the vehicle, Space Station accommodations, and facilities. All costs include the direct and indirect labor, material and overhead required to produce the first unit. Contractor fee is excluded.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
C	-400	OPERATIONS	This phase covers the operational period of the Orbital Transfer Vehicle program. In this portion of the life cycle the finished product is put into operation and is maintained in an operating condition for the duration of the program, or replaced. It includes all direct and indirect labor, materials (spares) and propellant costs required to operate and maintain the vehicles, facilities, and equipment developed and produced in the DDT&E and Production Phases. The operations phase is divided into two major divisions of work: operations support and launch support. Contractor fee is excluded.,
C	410	SPARES	Refers to the cost of procuring spares for the OTV program. The cost of spares transportation for Space-based OTVs is excluded; these costs are included in Space-Based Operations.
C	420	FLIGHT OPERATIONS	Refers to the costs incurred in operating and providing the ground based services of: Integrating the OTV into the Shuttle, tracking, command and control, vehicle recovery and maintenance of the OTV. Also includes cost of training replacement personnel and program management of the operations phase. Includes cost of the astronaut crew time for all maintenance and refurbishment operations which are performed in space. Transportation costs of logistics support for space based orbital transfer vehicles are also included. Included are spares delivery costs and the cost of delivering OTV payloads to LEO. Also includes the cost to transport propellants and gases into orbit for subsequent use by the OTV. This would normally be accomplished by tanker mode Shuttle flights, propellant scavenging from the STS, or by a dedicated bulk propellant delivery system such as a Shuttle-derived vehicle (SDV) or heavy-lift launch vehiucle (HLLV).

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
C	430	REFURBISHMENT	Includes the cost of any periodic overhaul and refurbishment of reusable flight hardware.

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
2	3.0	ORBITAL TRANSFER VEHICLE	This element refers to an orbital transfer vehicle designed to transfer payloads from low earth orbit to geosynchronous orbit and beyond.
3	3.0.1	PROGRAM MANAGEMENT	Refers to the costs associated with the prime contractor's centralized effort in areas of program planning, control and administration. Includes such tasks as program documentation, financial and manpower control, interfacing with the customer and other contractors and material and project management.
3	3.0.2	SYSTEM ENGINEERING AND INTEGRATION	This is the cost to define the engineering requirements necessary to direct an integrated approach to design, development and operations. Includes requirements definitions, mission payload analyses, preliminary design, design integration, system optimization, interface compatibility, design reviews, technical risk assessment, technical performance assessment, countdown analysis and system engineering data. Integration activities include intersystem engineering interface tasks with contractors and government agencies. Definition of Interface Control Documents, joint operating plans and interface control plans. Also includes development of program plans and analyses for: quality control, reliability, maintainability, producibility, transportability, safety, logistics and mass properties.
3	3.0.3	TOOLING & STE	This element consists of all effort and material necessary to provide the required tooling to permit fabrication and assembly of the structural elements of the protoflight OTV. It includes design, analysis, drawings, fabrication, assembly, installation, and validation of all tooling items and manufacturing aids.

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
3	3.0.4	SOFTWARE ENGINEERING	Refers to the cost of developing, analyzing, and verifying OTV and OTV interface software, including system and program design, program coding and debugging, program testing, integration and validation of programs.
3	3.0.5	SYSTEMS TEST OPERATIONS	Refers to the cost of performing system development tests of the Orbital Transfer Vehicle. Includes test operations as well as the hardware necessary to perform the tests, excluding test hardware for specific subsystems, whose costs are included in their design and development costs. Includes the costs of performing development tests using prototype hardware to acquire engineering data and confirm engineering hypotheses. The test operations include the detail planning, conduct, support, data acquisition and analysis, reports and materials consumed in ground and flight tests. Also included are any special test fixtures and related equipment, not categorized as GSE, necessary to conduct the required test program for the OTV or for OTV accommodations.
3	3.0.6	FLIGHT SUPPORT	This WBS element consists of all analyses, studies, and evaluations associated with determination and establishment of mission operation requirements, establishment of launch flight, and mission operations plans, and evaluation of associated procedures. It includes ground support, launch, and payload orbit analyses; payload crew activities planning; real-time mission planning; flight crew operations requirements (procedure and training); and flight support analysis for both the initial deployment flights as well as the operational period.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
3	3.0.7	INTEGRATION, ASSEMBLY & CHECKOUT	Refers to the integration and assembly of the OTV hardware elements and subsystems into an operational system. Includes all system calibration and checkout, as well as necessary acceptance testing.
3	3.1	STRUCTURE & MECHANISMS	This element refers to the cost of the OTV structural subsystems.
4	3.1.1	BODY SHELL	This element is the cost of the system of mechanical members whose primary function is to rigidize the system and to provide the thrust load path (excluding integral tankage).
4	3.1.2	FUEL TANKS	This is the cost of the fuel tanks (liquid hydrogen or MMH). This includes both integral and non-integral tanks.
4	3.1.3	OXIDIZER TANKS	This is the cost of the oxidizer tanks (liquid oxygen or N_2O_4). This includes both integral and non-integral tanks.
4	3.1.4	SUPPORT STRUCTURE	Includes the cost of the support struts which provide structural support between the propellant tanks and the primary or adapter structures.
4	3.1.5	THRUST STRUCTURE	This is the cost of the thrust structure which is the major load bearing element for the main engine(s). It is comprised of engine mounting provisions, thrust struts, actuator attach points and mounting supports for engine fluid and electrical interface lines.
4	3.1.6	EQUIPMENT MOUNTING	This element includes the cost of the structure supporting any externally mounted equipment on the body shell and the structure housing the various avionics modules.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	3.1.7	PAYLOAD INTERFACE	This is the cost of the structure and securing devices of the interface used between the vehicle and a single payload or between the multiple payload carrier and its respective payloads.
4	3.1.8	DOCKING STRUCTURE	This cost element refers to the mechanical attachment fittings on the OTV enabling use of the Shuttle RMS and the Space Station RMS for maneuvering the OTV in those vicinities.
4	3.1.9	UMBILICAL PANEL	This element is the cost of all interface panels required for automatic latching and unlatching of the OTV to the Shuttle/Space Station or tanksets where applicable.
4	3.1.10	ATTACHMENT FITTINGS	This is the cost of the fittings on the vehicle required for mounting to the support structure with the launch vehicle.
4	3.1.11	MICROMETEOROID SHIELD	This is the cost of the layers of multi-layered insulation used to assure against micrometeoroid damage.
3	3.2	AEROASSIST DEVICE	This cost element refers to the aerodynamic surfaces, thermal protection support structure and deployment mechanisms of the aeroassist device.
4	3.2.1	TRUSS STRUCTURE	This element refers to any integral aerobrake structure, any support structure for a flexible TPS, and any support structure or pressurization tanks for the ballute device.
4	3.2.2	FLEXIBLE THERMAL PROTECTION SYSTEM	This cost element includes the flexible thermal protection system functioning as an insulating aerodynamic surface. (i.e., Nextel Fabric).

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	3.2.3	FIXED THERMAL PROTECTION SYSTEM	This cost element includes the fixed thermal protection system functioning as an insulating, aerodynamic surface (i.e. thermal tiles).
4	3.2.4	BALLUTE	This cost element refers to the flexible ballute functioning as the insulating aerodynamic surface (inflatable).
4	3.2.5	ACTUATORS & MECHANISMS	This cost element includes all actuators and mechanisms required to deploy, control, or retract the aerobrake and those required for any "door" opening and closing.
3	3.3	PROPULSION SYSTEM	This element refers to all components of the main propulsions system and the auxiliary reaction control system.
4	3.3.1	MAIN ENGINES	This element refers to the costs of all activities necessary to develop and produce rocket engines, and includes all engineering and development activities, test hardware and engines, test operations and propellants consumed by the engine contractor in this activity. (Does not include "cluster" testing of complete engine system installation, any activities at vehiucle contractor facility or engines to support vehicle test.)
4	3.3.2	MAIN PROPULSION SYSTEM	This element encompasses the components of the primary propulsion system that provides the acceleration necessary to give the OTV orbital velocity and/or the deceleration of the vehicle for de-orbit maneuvers.
5	3.3.2.1	THRUST VECTOR	This element refers to the system with the capability to vector the thrust to control the flight trajectory.

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.3.2.2	PRESSURIZATION/ PNEUMATIC SYSTEM	This element is composed of all lines, valves, ducts, bellows, disconnects, and other components that take pressurization gases from the engine to the main fuel tank, and the lines, valves, ducts, bellows, storage tank and other components which provide pressurization gas to the oxidizer tanks. It also consists of those components that are required to provide for propellant vent and for carrying pressurization gas for the main oxidizer and main fuel tanks for dumping propellant overboard. Also included are those provisions required to provide gas purge of required vehicle areas.
5	3.3.2.3	PROPELLANT UTILIZATION	This assembly provides the capability to control the mixture ratio of oxidizer to fuel.
5	3.3.2.4	FEED, FILL, VENT AND DRAIN - FUEL	This element is the cost of all lines, valves, ducts, bellows, disconnects, propellant acquisition system, mass gauging and other components that transfer fuel from the tanks to the main engine. Also included are all lines, ducts, valves, and other components required to fill and drain the main fuel tanks between the interface panel with the Space Station disconnect and the main fuel tanks which are filled and drained.
5	3.3.2.5	FEED, FILL, VENT & DRAIN-OXIDIZER	This element refers to the systenms described in 3.3.2.4.
4	3.3.3	AUXILIARY PROPULSION	This element includes all components of the OTV Reaction Control System.
5	3.3.3.1	REACTION CONTROL THRUSTERS	This element refers to the reaction control engines.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.3.3.2	PROPELLANT TANKS	This refers to gas generators, pumps, turbines, heat exchangers, and storage tanks for the fuel and oxidizer required for the reaction control thrusters.
5	3.3.3.3	PRESSURIZATION TANKS	This refers to the storage capacity for the gas required to pressurize the fuel and oxidizer for the RCS Thrusters.
5	3.3.3.4	PLUMBING	This element encompasses the propellant lines and values supporting the reaction control system.
3	3.4	THERMAL CONTROL	The thermal control system consists of both active and passive means of controlling heat transfer within the OTV system. Thermal control devices or provisions which are an inherent part of a component of another subsystem are included within that subsystem and are excluded from this element.
4	3.4.1	INSULATION	This element includes all multilayer insulation and foam insulation required for the vehicle propellant tanks.
5	3.4.1.1	FUEL TANKS	This element includes all insulation required for the fuel tanks.
5	3.4.1.2	OXIDIZER TANKS	This element includes all insulation required for the oxidizer tanks.
5	3.4.1.3	AVIONICS/POWER	Refers to the design and development cost of active and passive thermal control subsystems for the avionics and power system, including insulation, cover panels, bonding material, and local ablators.
4	3.4.2	PURGE	Includes the cost of the OTV purge system used to vacate propellants from ground-based OTV tanks and feedlines.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.4.2.1	CONTROL	This element is the cost of designing and developing the purge control system (ground-based OTVs only).
5	3.4.2.2	FUEL TANK PURGE	This includes the cost of the fuel tank purge system, which is applicable only to ground-based OTVs.
5	3.4.2.3	OXIDIZER TANK PURGE	This includes the cost of the oxidizer tank purge system, which is applicable only to ground-based OTVs.
5	3.4.2.4	AVIONICS	
3	3.5	GUIDANCE AND NAVIGATION	Includes design, development, test and integration of all elements described below. Software and hardware are included.
4	3.5.1	DRIVE ELECTRONICS	Includes the cost of developing and testing the OTV subsystem control voter, which includes some signal processing/remote multiplex capability for subsystems not on the system bus. The controller/voter also takes commands from the three guidance control processors, votes 2 out of three on the inputs and controls the RCS and TVC with the voted output.
5	3.5.1.1	RCS	This element refers to the drive electronics to provide control for the RCS.
5	3.5.1.2	TVC	This element refers to the drive electronics to provide control for the TVC.

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	3.5.2	INERTIAL MEASUREMENT UNIT	Refers to the cost of designing and developing the OTV Inertial Measurement Unit, which contains the ring laser gyros and accelerometers that provide a space-fixed coordinate reference for attitude and velocity control. This information is transmitted from the IMU to the guidance control processor.
4	3.5.3	STAR TRACKER	Refers to the cost of designing and developing, or adapting for use on the OTV, the electro-optial platform that uses a known star as a reference for providing attitude and updates. Includes selection of tracker location, update times, and update techniques for provision of inertial update data to the guidance control processor and IMU.
4	3.5.4	GPS RECEIVER	This element is the cost of development and test of the GPS antennas and receiver/ processor, including antenna link analysis, GPS observability analysis, definition of receiver/process requirements for geosynchronous missions, and integration of the receiver with the guidance control processor. The GPS processor will provide a state vector update to the guidance control processor.
4	3.5.5	RENDEZVOUS/ DOCKING SYSTEM	The element is the design and development cost of hardware used for coordinating the operations of the guidance control processor, proximity safe system, telemetry and propulsion subsystem, and ranging and tracking devices during OTV rendezvous and docking operations with the STS and Space Station.
3	3.6	COMMUNICATIONS AND DATA HANDLING	Includes design, development and testing of the communications, data management, video, subsystems as described below. This also includes the integration of these subsystems with each other vehicle subsystems such as GNC and thermal control.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	3.6.1	COMMUNICATIONS	This element refers to the design, integration and development cost of the communications subsystems defined below. These costs include all direct and indirect prime and subcontractor labor, materials and G&A. Costs also include component and subsystem checkout and test costs at the subcontractor level.
5	3.6.1.1	TRANSPONDERS	Includes the cost of developing the transponders used for communication and data links between the OTV and other vehicles. Existing equipment may be modified so the OTV can use TDRS in high Earth orbits.
5	3.6.1.2	AMPLIFIERS	This is the cost of developing and testing amplifiers used to enhance telemetry signals transmitted to the OTV antennas. Candidate amplifiers under consideration include traveling wave tube and solid state amplifiers.
5	3.6.1.3	ANTENNAS	Includes design and development of steerable antennas and other antennas used to communicate with the ground, Space Station, Space Shuttle, TDRS, OMV, and GPS. This includes investigation of the availability of GPS and TDRS signals at high altitudes and testing of alternate antenna locations.
5	3.6.1.4	RF SWITCH	Refers to the integration and testing of an RF switch used to select different antennas on the vehicle.
5	3.6.1.5	TRANSMITTER	Includes the integration and test of a device used to change electrical information to RF signals.
5	3.6.1.6	RECEIVER	Includes the integration and test of a device used to change RF signals to electrical information.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.6.1.7	SIGNAL PROCESSOR	Includes the design and development cost of hardware for the control status processor (or signal processor), which implements uplinked commands, processes uplinked data, collects data from data bases, and formats telemetry for downlink. Interfaces to the vehicle telemetry subsystem and data busses are also included.
4	3.6.2	DATA MANAGEMENT	Includes the design, development, integration, and test of the data management system whose elements are described below. This system processes, stores, acquires, and controls distribution of information between vehicle subsystems. Software to perform this task is included.
5	3.6.2.1	COMPUTER	This element is the design and development cost of the guidance control processor, which receives information from the IMU, star tracker, and GPS. These signals are processed to control the coast, powered, rendezvous, and aeromaneuvering phases of flights. This function includes data bus control.
5	3.6.2.2	SIGNAL CONDITIONING UNIT	This includes the design, development, and test of a device that takes instrumentation signals and puts them on the system bus after conditioning them so they are compatible with the system bus. This function is included in the controller/voters.
5	3.6.2.3	COMPUTER INTERFACE UNIT	Includes the design, development, integration and test of devices that allow individual elements to talk to the system bus and bus controller.
5	3.6.2.4	REMOTE INTERFACE UNIT	Includes the development integration, and test of devices used to multiplex and condition instrumentation signals from various parts of the vehicle.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.6.2.5	BUS COUPLERS	This is the design and development cost of optical fibers, transmitters, receivers, bus interface devices, harnesses, reflectors, connectors, and branches, which are used for communication within the vehicle.
5	3.6.2.6	MASS STORAGE UNIT	Refers to the cost of designing and developing the Zone of Entry/ Exclusion recorder, which records inertial, thermal and atmospheric data during the communication blackout experienced during atmospheric entry.
5	3.6.2.7	INSTRUMENTATION	This element summarizes the cost of designing and developing the instrumentation equipment. It includes the required sensors, transducers and circuitry to monitor environmental conditions aboard the OTV within any of the subsystems. It also includes the design and development of the propellant utilization (PU) and propellant loading instrumentation (PLIS) system. The system consists of the controls which minimize the residual weight of one propellant at the depletion of the other. It consists of PU tank probes, LO_2 and LH_2 tank sensors and engine servopositioners to control propellant flow to the engines. This element excludes the computational and data conditioning devices.
5	3.6.2.8	DATA BUS CONTROL UNIT	Refers to the integration and test of the unit that controls formatting, timing, protocol, and communication on the system data bus. This function is done by the Guidance Control Processor (or computer).
4	3.6.3	VIDEO	Refers to the development, integration and test of the video elements described below.
5	3.6.3.1	TV CAMERA	Includes the integration and test of the camera used to acquire visual information.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.6.3.2	CONTROL UNIT	Includes the design, development, test, and integration of a device to control the use, pointing, lighting, and data distribution of the video system. It must be remotely commandable via the RF system or, in the manned module case, via hardline.
5	3.6.3.3	VIDEO SWITCH	Refers to the integration and test of a device used to select cameras in use.
5	3.6.3.4	IMAGE PROCESSOR	Refers to the development and test of hardware and software required for image processing. This includes video processing and possibly the automatic recognition and processing of particular images.
5	3.6.3.5	TV LIGHTS	Includes the integration and test of lighting to provide sufficient illumination for the TV cameras.
5	3.6.3.6	POSITION LIGHTS	Includes the integration and test of lighting to provide reference for OTV cameras and observers.
5	3.6.3.7	ELECTRICAL UNIT	Includes the design development, test and integration of a system that distributes power, information and commands among video elements.
3	3.7	ELECTRICAL POWER	Includes design, development and testing of primary electrical power, secondary electrical power, and power interface subnsystems as described below. This also includes the integration of these sub-systems with each other and with other vehicle subsystems such as GN&C nad thermal control.
3	3.7.1	PRIMARY ELECTRICAL POWER	Refers to the design and development of the fuel cell power source and power distribution system as described below.
4	3.7.1.1	FUEL CELL SYSTEM	Includes the cost of designing and developing the fuel cell system, including fuel cells, tanks, plumbing, and valves.
4	3.7.1.2	BATTERIES	This element is the cost of design and development of batteries used for energy storage.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.7.1.3	CABLING AND HARNESS	Includes the design, development, integration and test of the power busses. These busses distribute different types of electrical power to all users on the vehicle.
5	3.7.1.4	DISTRIBUTOR	Includes the design, development, integration and test of the device which takes electrical power from the fuel cell or support power, conditions it, and routes it to all users on different parts of the vehicle.. This device is commandec by the controller to turn busses on and off and regulate the level of power on the busses.
5	3.7.1.5	POWER SWITCH	Includes the integration and test of a device that switches between the two fuel cells at the command of the energy control unit.
5	3.7.1.6	CHARGER/REGULATOR	Refers to the design, development, test, and integration of the Energy Control Unit. This unit monitors fuel cell status and controls fuel cell operations.
3	3.8	GROUND BASED OPERATIONS	This element refers to the recurring operations performed at the ground based launch and refurbishment sites required to sustain the flights of the orbital transfer vehicle.
4	3.8.1	GROUND TRANSPORTATION	This element refers to the cost of ground transportation of vehicle system elements between the production, refurbishment, processing and launch sites.
4	3.8.2	OTV TEST	This element refers to the cost of the inspection and analysis required to determine the flight readiness status if vehicle hardware, upon delivery to the launch site from production or refurbishment, during final launch checkout, and after flight recovery.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.8.2.1	OTV SYSTEM	This element refers to the cost of performing system level tests & analysis.
5	3.8.2.2	STRUCTURE & MECHANISMS	This element refers to the cost of performing tests & analyses required to assess the flight readiness of the structural and mechanical subsystems (3.1).
5	3.8.2.3	AEROASSIST DEVICE	This element refers to the cost of performing tests & analyses required to assess the flight readiness of the aeroassist device (3.2).
5	3.8.2.4	PROPULSION SYSTEM	This element refers to the cost of performing tests & analyses required to assess the flight readiness of the main & auxiliary propulsion system (3.3).
5	3.8.2.5	THERMAL CONTROL	This element refers to the costs of performing tests & analyses required to assess the flight readiness of the thermal protection and control systems (3.4).
5	3.8.2.6	GUID NAV & CNTRL	This element refers to the costs of performing tests & analyses required to assess the flight readiness of the guidance, navigation and control system (3.5).
5	3.8.2.7	ELECTRICAL SYSTEM	This element refers to the costs of performing tests & analyses required to assess the flight readiness of the electrical system (3.6).
5	3.8.2.8	SOFTWARE	This element refers to the costs of performing tests & analyses required to assess the flight readiness of the vehicle software (3.0.4).

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	3.8.3	OTV MAINTENANCE	This element refers to the cost of performing routine maintenance and periodic refurbishment on the orbital transfer vehicle in order to maintain flight readiness.
5	3.8.3.1	OTV SYSTEM	This element refers to the cost of maintaining the system level characteristics and interfaces of the OTV system.
5	3.8.3.2	STRUCTURE & MECHANISMS	This element refers to the cost of maintaining the structural & mechanical systems (3.1).
5	3.8.3.3	AEROASSIST DEVICE	This element refers to the cost of maintaining the aeroassist device (3.2).
5	3.8.3.4	PROPULSION SYSTEM	This element refers to the cost of maintaining the propulsion system (3.3).
5	3.8.3.5	THERMAL CONTROL	This element refers to the cost of maintaining the thermal protection & control systems (3.4).
5	3.8.3.6	GUID,NAV & CNTRL	This element refers to the cost of maintaining the guidance, navigation and control system (3.5).
5	3.8.3.7	ELECTRICAL SYSTEM	This element refers to the cost of maintaining the electrical system (3.6).
5	3.8.3.8	SOFTWARE	This element refers to the cost of maintaining the OTV flight and ground software (3.0.4).
4	3.8.4	INTEGRATION & LAUNCH PREPARATION	This element refers to the cost of any final integration, assembly and checkout required for certification of launch readiness.

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.8.4.1	OTV ASSEMBLY	This element refers to the cost of vehicle and payload integration, assembly & checkout (I,A, C/O)
5	3.8.4.2	TANKSETS	This element refers to the cost of I, A & C/O of the tanksets & fluid system interfaces (3.1, 3.3).
5	3.8.4.3	AEROASSIST DEVICE	This element refers to the cost of I, A, & C/O of the aeroassist device (3.2).
5	3.8.4.4	SOFTWARE	This element refers to the cost of loading the flight software for the Mission (3.0.4).
5	3.8.4.5	PAYLOAD	This element refers to the cost of I, A & C/O of the cargo system.
5	3.8.4.6	FUELING	This element refers to the cost of fueling the OTV before flight.
4	3.8.5	LAUNCH & MISSION CONTROL	This element refers to the cost of real-time launch & mission control of the vehicle.
4	3.8.6	RECOVERY AND DESERVICING	This element refers to the cost of the procedures to recover, deservice and stow the OTV system after flight.
5	3.8.6.1	BERTHING	This element refers to the cost of mating the OTV with ground handling and storage equipment.
5	3.8.6.2	DESERVICING	This element refers to the cost of venting, dumping, purging all lines & tanks of hazardous fluids and the cost of safing any hazardous ordinance systems after flight.
5	3.8.6.3	STORAGE	This element refers to the cost of any disassembly and stowage of vehicle components upon arrival to the ground processing site.

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
3	3.9	SPACE BASED OPERATIONS	This element refers to the recurring operations performed at space based launch and refurbishment sites required to sustain the flights of the orbital transfer vehicle.
4	3.9.1	SPACE TRANSPORTATION	This element refers to the cost of transporting the OTV on orbit.
5	3.9.1.1	LOW EARTH ORBIT DELIVERY	This element refers to the cost of transporting the OTV from earth to low earth orbit.
5	3.9.1.1	SPACE STATION MANEUVERING	This element refers to the cost of transporting the OTV within the vicinity of its space station accommodations utilizing an orbital maneuvering vehicle.
4	3.9.2	OTV TEST	This element refers to the cost of the inspection and analysis required to determine the flight readiness status of vehicle hardware delivery to the space based site from production or refurbishment, during final launch checkout, and after flight recovery.
5	3.9.2.1	OTV SYSTEM	This element refers to the cost of performing system level tests & analyses.
5	3.9.2.2	STRUCTURE & MECHANISMS	This element refers to the cost of performing tests & analyses required to assess the flight readiness of the structural and mechanical subsystems (3.1).
5	3.9.2.3	AEROASSIST DEVICE	This element refers to the cost of performing tests & analyses required to assess the flight readiness of the aeroassist device (3.2).
5	3.9.2.4	PROPULSION SYSTEM	This element refers to the cost of performing tests & analyses required to assess the flight readiness of the main & auxiliary propulsion system (3.3).

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.9.2.5	THERMAL CONTROL	This element refers to the costs of performing tests & analyses required to assess the flight readiness of the thermal protection and control systems (3.4).
5	3.9.2.6	GUID NAV & CNTRL	This element refers to the costs of performing tests & analyses required to assess the flight readiness of the guidance, navigation and control system (3.5).
5	3.9.2.7	ELECTRICAL SYSTEM	This element refers to the costs of performing tests & analyses required to assess the flight readiness of the electrical system (3.6).
5	3.9.2.8	SOFTWARE	This element refers to the costs of performing tests & analyses required to assess the flight readiness of the vehicle software (3.0.4).
4	3.9.3	OTV MAINTENANCE	This element refers to the cost of performing routine maintenance and periodic refurbishment on the orbital transfer vehicle in order to maintain flight readiness.
5	3.9.3.1	OTV SYSTEM	This element refers to the cost of maintaining the system level characteristics and interfaces of the OTV system.
5	3.9.3.2	STRUCTURE & MECHANISMS	This element refers to the cost of maintaining the structural & mechanical systems (3.1).
5	3.9.3.3	AEROASSIST DEVICE	This element refers to the cost of maintaining the aeroassist device (3.2).
5	3.9.3.4	PROPULSION SYSTEM	This element refers to the cost of maintaining the propulsion system (3.3).

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
5	3.9.3.5	THERMAL CONTROL	This element refers to the cost of maintaining the thermal protection & control systems (3.4).
5	3.9.3.6	GUID,NAV & CNTRL	This element refers to the cost of maintaining the guidance, navigation and control system (3.5).
5	3.9.3.7	ELECTRICAL SYSTEM	This element refers to the cost of maintaining the electrical system (3.6).
5	3.9.3.8	SOFTWARE	This element refers to the cost of maintaining the OTV flight software (3.0.4).
4	3.9.4	INTEGRATION & LAUNCH PREPARATION	This element refers to the cost of any final integration, assembly and checkout required for certification of launch readiness on orbit.
5	3.9.4.1	OTV ASSEMBLY	This element refers to the cost of on-orbit vehicle payload integration, assembly & checkout (I,A,C/O).
5	3.9.4.2	TANKSETS	This element refers to the cost of on-orbit I,A & C/O of the tanksets & fluid system interfaces (3.1, 3.3).
5	3.9.4.3	AEROASSIST DEVICE	This element refers to the cost of on-orbit IA. & C/O of the Aeroassist device (3.2).
5	3.9.4.4	SOFTWARE	This element refers to the cost of on-orbit loading of the flight software for the Mission (3.0.4).
5	3.9.4.5	PAYLOAD	This element refers to the cost of on-orbit I, A & C/O of the cargo system.
5	3.9.4.6	FUELING	This element refers to the cost of on-orbit fueling the OTV before flight.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	3.9.5	LAUNCH & MISSION CONTROL	This element refers to the cost of on-orbit real-time launch & mission control of the vehicle.
4	3.9.6	RECOVERY AND DESERVICING	This element refers to the cost of the controlling procedures to recover, deservice and stow the OTV system after flight.
5	3.9.6.1	BERTHING	This element refers to the cost of controlling mating with OTV ground handling equipment.
5	3.9.6.2	DESERVICING	This element refers to the cost of controlling venting, dumping, purging all lines & tanks of hazardous fluids and the cost of safing any hazardous ordinance systems after flight.
5	3.9.6.3	STORAGE	This element refers to the cost of controlling any disassembly and stowage of vehicle components upon arrival to the ground processing site.
3	3.10	SUPPORT EQUIPMENT	This element refers to the cost development and procurement of support equipment required for production, processing, transportation and launch of an OTV.
4	3.10.1	GROUND SUPPORT	This element summarizes all effort and material required to define, design, develop, test and qualify, procure, fabricate, assemble, and check out all new or modified ground support equipment (GSE). It includes all deliverable GSE hardware and its associated software required to support the OTV system during the development, manufacturing, and operations phases, and all effort and material required for GSE maintenance. It includes all necessary handling and transportation equipment; servicing equipment; functional checkout equipment and maintenance and auxiliary equipment.

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	3.10.2	AIRBORNE SUPPORT EQUIPMENT	This element includes the equipment required to mate the OTV with the cargo delivery vehicle and to support the operation of the OTV in orbit. It summarizes tasks and services required to mate the OTV with the Shuttle, link with and separate from it, and to support mating of multiple payloads with the OTV and STS. Included is the equipment for operational docking/undocking of the OTV and Shuttle, abort provisions, alignment and energy absorption, retraction/extension support, reentry purge, avionics interface, umbilical disconnects in the fluid/electrical interface, and on-orbit assembly tools and equipment.
5	3.10.2.1	MULTIPLE PAYLOAD CARRIER	This element refers to the payload carrier designed to mount to the payload interface ring on the OTV providing attach points for two to four payloads.
5	3.10.2.2	STS SUPPORT EQUIPMENT	Includes the airborne support equipment required for delivery of the OTV to LEO on the STS, such as structural and mechanical interfaces between the OTV and the cargo bay, electrical connections to the STS power system, data busses, and deployment/assembly equipment.
5	3.10.2.3	AFT CARGO CARRIER	This element is the aft cargo carrier (ACC) attached to the underside of the Shuttle external fuel tank and used to deliver certain OTV configurations to orbit.
5	3.10.2.4	STS/SDV DELIVERY TANK	This element refers to any tank or dewar used to transport propellant in the STS Cargo Bay or in the SDV. This includes the fluid management system associated internally and externally with these tanks.
2	4.0	GROUND BASED FACILITIES	This element includes the cost of the architectural engineering, design, construction, and activation of ground based facilities. These facilities include non-vehicle specific equipment.

SECTION 2

OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
3	4.1	INFRASTRUCTURE	This element refers to the components of the launch site infrastructure such as roads, fences, guard stations, office buildings, etc.
3	4.2	LOGISTICS	This element refers to the spares storage & retrieval system for the OTV.
3	4.3	PROPELLANT	This element refers to the propellant manufacturing and storage facilities required to supply the OTV system.
3	4.4	MANUFACTURING	This element refers to the facilities required for vehicle system hardware fabrication and assembly.
3	4.5	ASSEMBLY AND CHECKOUT	This element refers to the final assembly and checkout facilities required at the OTV ground based launch sites.
3	4.6	PAYLOAD INTEGRATION	This element refers to the integration facility utilized for payload checkout, integration and manifest operations.
3	4.7	VEHICLE MAINTENANCE	This element refers to the facilities required to perform routine maintenance and periodic overhaul on the vehicle system elements.
3	4.8	MISSION CONTROL	This element refers to the facilities required for flight planning and real time mission control.
2	5.0	SPACE STATION ACCOMMODATIONS	This element refers to Space Station accommodations required for space-based OTV turnaround, including maintenance and servicing facilities and a propellant storage depot.
3	5.1	OTV HANGAR	Includes all elements comprising the hangar provisions for on-orbit protection of the Space-based OTV (SBOTV) and crewpersons involved in EVA maintenance operations. Includes the hangar support structure, meteoroid/debris protection, and Space Station attachment structure.

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	5.1.1	TRUSS STRUCTURE	Refers to the structure that attaches the OTV hangar to the Space Station and that supports the meteoroid/debris protection, docking/berthing mechanisms, and handling mechanisms.
4	5.1.2	FRAMES/ATTACHMENT HARDWARE	This element includes the frames, attachment hardware and door hinges that support the meteoroid/debris protection panels in conjunction with the truss structure.
4	5.1.3	METEOROID/DEBRIS PROTECTION	Refers to the material used for meteoroid/debris protection.
4	5.1.4	MECHANISMS	Includes the mechanisms used to operate the doors of the OTV hangar.
4	5.1.5	TANK MODULE STORAGE	Refers to the provisions for storage of the tank modules, within or external to the OTV hangar.
3	5.2	BERTHING/POSITIONING MECHANISM	This element is the mechanism and fixture required for berthing, positioning, and handling of the SBOTV, including propellant transfer and payload integration aids, both internal and external to the OTV hangar.
4	5.2.1	BERTHING/PROPELLANT TRANSFER MECHANISM	Refers to the mechanisms required for berthing of the OTV at the Space Station and for transfer of propellants from the storage tank supply lines to the vehicle.
4	5.2.2	ROTATION DEVICE	This element includes the mechanisms required for supporting and rotating the OTV, up to 360^{o}.
4	5.2.3	RMS RAILS/DRIVE MECHANISM	Includes the robotic arm rails and drive mechanisms used for remote servicing of the SBOTV within the OTV hangar.
4	5.2.4	PAYLOAD MATING FIXTURE	Refers to the support fixtures required for mating of OTV payloads with the vehicle.

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	5.3.8	METEOR/DEBRIS PROTECTION	Refers to the materials used for meteoroid and debris protection of the propellant storage system.
4	5.3.9	POWER/UTILITY INTERFACE	Refers to the electrical, mechanical and hydraulic interface to the OTV hangar.
3	5.4	CONTROL AND CHECK-OUT EQUIPMENT	This element refers to the cost of checkout equipment required for pressurization operations, environmental monitoring, maintenance tasks and mission control.
4	5.4.1	CONTROLS AND DISPLAYS-PRESSURIZED	Includes all controls and displays required internal to a pressurized environment such as the space station.
4	5.4.2	POWER AND DATA DISTRIBUTION	This element refers to the power & data distribution system and any interfaces required between on orbit platforms.
4	5.4.3	REMOTE LEAK DETECTORS	Refers to the leak detection system utilized to monitor gas and fluid leaks within range of the orbiting accommodations.
4	5.4.4	CONTROLS & DISPLAYS-UNPRESSURIZED	This element refers to the controls and displays required in unpressurized environments.
3	5.5	MAINTENANCE EQUIPMENT	This element includes all maintenance equipment and tools required for manned and remote servicing of the OTV.
4	5.5.1	RACKS AND STORAGE	Refers to the racks and storage provisions for tools and associated OTV maintenance equipment, and OTV flight hardware.
4	5.5.2	ROBOTIC EQUIPMENT	Includes the remote manipulator system (robotic arm) and associated attachments, including those already in place at the Space Station, that are used for OTV berthing, translation, positioning, and ORU removal and replacement.

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
3	5.3	PROPELLANT/PRESSURANT STORAGE	This element includes the facilities and equipment required for transfer of OTV propellants from delivery systems, storage and conditioning of propellants at the Space Station, and transfer of propellants from storage to the OTV and back to storage.
4	5.3.1	STRUCTURE	Includes the supplementary structures required for supporting propellant storage tanks at the Space Station, including beams and tank supports.
4	5.3.2	OXIDIZER TANKS(S)	Refers to the oxidizer storage tanks for the OTV, including the tank wall structure and all propellant management components within the tanks, such as the acquisition system, gauging system, thermodynamic vent system and slosh baffles.
4	5.3.3	FUEL TANK (S)	Includes the OTV fuel storage tanks at the Space Station, including external and internal components such as those defined for the oxidizer tanks in element 2320 above.
4	5.3.4	PRESSURANT TANK/ GAS GENERATOR	This element includes the storage and pressurization tanks for the boil-off propellant being pressurized for Space Station users. This includes all propellant management components within the tanks.
4	5.3.5	PLUMBING	Includes the cost of plumbing lines, insulation, valves, and supports for the resupply lines required for propellant transfer from delivery vehicles to the storage tanks and from the storage tanks to the OTV berthing station.
4	5.3.6	REFRIGERATION	Refers to the refigeration and reliquefaction equipment required for propellant conditioning at the Space Station.
4	5.3.7	INSULATION/VAPOR-COOLED SHIELD	This element is the multi-layer insulation and a vapor-cooler shield used for thermal insulation of the fuel and oxidizer storage tanks.

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OTV WBS DICTIONARY

WBS LVL	ELEMENT NUMBER	HARDWARE ELEMENT DESIGNATION	DESCRIPTION
4	5.5.3	TOOLS	These are the tools used by crewpersons and in conjunction with robotic equipment for performance of OTV maintenance and servicing tasks.
4	5.5.4	ASTRONAUT SUPPORTS/ RESTRAINTS	Refers to the foot restraints and other equipment required to support and restrain crewpersons while performing maintenance and servicing tasks.
4	5.5.5	LIGHTING	This refers to the lighting system in and around the OTV hangar to support maintenance and servicing tasks.
4	5.5.6	TV CAMERAS	This is the video equipment used to support remote servicing of the OTV within the hangar.

3.0 Cost Estimating Approach Methodology and Rationale & Groundwork

Cost estimating for the technologies described in Vol. III have been developed using parametric cost estimating techniques. In this approach all cost elements associated with the project or technology to be estimated are identified including both hardware as well as programmatic elements such as Program Management, System Engineering, Test, etc. Definition and descriptions of the project elements are then used to establish costs by means of a cost estimating relationship (CER) that relates cost to a driving parameter such as weight, power, size, etc. The summation of these cost elements then represents the total cost of the project under analysis. Cost for both nonrecurring (design and development) and recurring (unit protection) are estimated.

Because of the very brief definition information available for the technologies being investigated, the cost estimates are necessarily preliminary. Time of the cost estimates summarized in Section 4.0 and 6.0 have been updated from past or current related effects. The tankers in Section 4 are derived from a more extensive cost analysis conducted in the Long Term Cryogenic Storage Facility System Study conducted by GD in 1987. Similarly, the Docking and Berthing TDM (Section 6.0) represents an update of the work conducted in 1984 for the "OTV Servicing Study".
The groundrules used during this cost analysis are listed below:

Groundrules and Assumptions

- All costs are ROM for planning purposes only.
- Costs are in consistant FY 1987 M $.
- No fee, management resume, or contingency are included.
- The Propellant Transfer Storage and Reliquification technology estimates are based on the Large Tank Cryogenic Storage Facility Study (NAS8-36612).
- All other technologies are based on very preliminary and brief definitions.
- No Government support or STS costs are included.
- No flight or sortie operations costs are included.
- ELV vehicle costs are included with appropriate technologies.

4.0 Cost Estimates

Brief cost analyses have been conducted for the operations in Vol. II and each of the technologies developed and recommended during this study. The technology cost estimates are presented in Sections 3 through 7 in Volume III - Technology Development Plan. It was deemed more appropriate to include the costs in conjunction with all definition and description of the technologies that were used in the development of the cost estimates and therefore necessary for their understanding.